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Thesis 10



Hjelmroos-Ericsson, Mervi:
Holocene development of
Lake Wielkie Gacno area,
northwestern Poland



Lund 1981

HOLOCENE DEVELOPMENT OF LAKE WIELKIE GACNO AREA;
NORTHWESTERN POLAND

av

Mervi Hjelmroos-Ericsson

Fil.kand., Lu

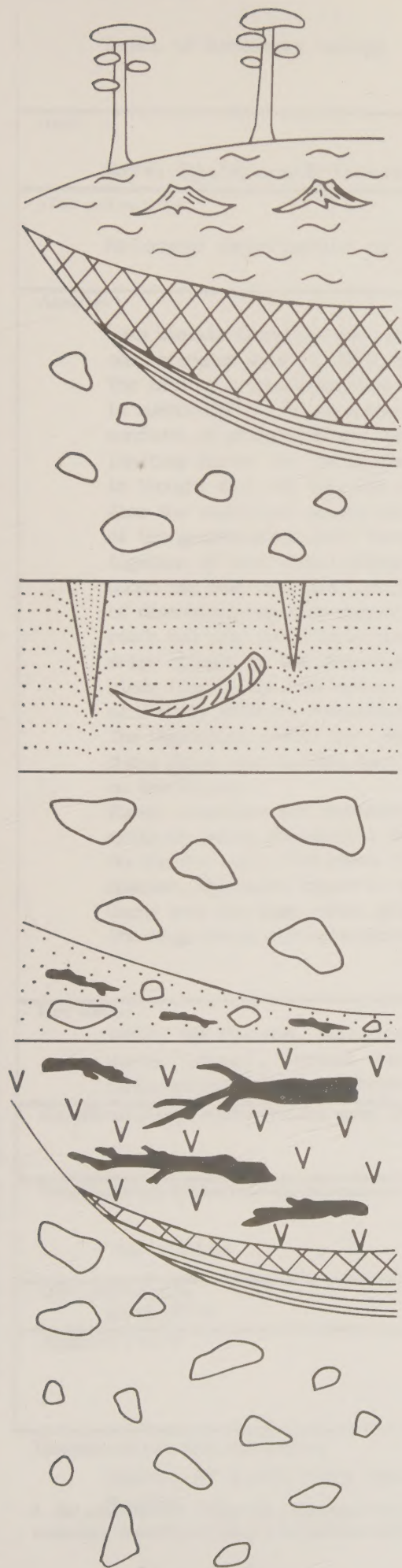
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THESIS 10

HJELMROOS-ERICSSON, M.:
HOLOCENE DEVELOPMENT OF
LAKE WIELKIE GACNO AREA,
NORTHWESTERN POLAND



A contribution to
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Abstract Lake Wielkie Gacno has been investigated palaeoecologically and represents one reference site for IGCP, Subproject 158 B, in NW Poland. The lake is a low-productive, oligotrophic, so-called <u>Lobelia</u> - lake which is surrounded by inland dunes and poor, sandy soils. In the lake water the contents of phosphorus and carbonates are considerably high, but as a delimiting factor for the productivity the nitrogen supply is very low. It is thought that the lake has got its nutrients through the ground-water. Also the vegetation around the lake has been very sensitive to the changes of the ground-water level throughout the Holocene. According to the investigation of water-level changes it is evident that the whole Lake Wielkie Gacno has been shallower until the Late Atlantic chronozone. The results of diatom analyses also support this theory. Evidence of five low-water periods has been established during the Holocene, indicating five periods of drier climate in the investigated area. The first and third low-water periods (during the Pre-boreal and around the chronozone boundary Late Boreal / Early Atlantic respectively), have been the strongest ones. The vegetation around the lake has had a mosaic character: on poor, sandy dunes <u>Pinus</u> associations have dominated while broad-leaved trees occurred on the slopes. Forest zonations are reconstructed for each chronozone. All important and critical pollen floristical levels are radiocarbon-dated, 23 in all. During the last 5 500 years five anthropogenous phases have been found. However, the human impact on the natural vegetation in the Lake Wielkie Gacno area has been rather slight, except in the last hundred years, when the large-scale pine-plantations have grown up.			
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I. INTRODUCTION

The palaeoecological investigation of Lake Wielkie Gacno represents one reference site in the International Geological Correlation Programme (IGCP) - Project No 158, Subproject B: "Palaeohydrological changes in the temperate zone in the last 15 000 years". The object of this IGCP-project is to analyse, in a high degree of detail, palaeoecological reference profiles which have a chronology based on accurate absolute datings from different type regions, in this case one type region in NW-Poland (Fig. 1) (cf. Project guide for IGCP 158 b, ed. Berglund 1979). It has been recommended that each country or region belonging to the project should be subdivided into natural geographical areas. Every such area should consist of a network of reference areas for palaeoecological research. An example of this is seen in Fig. 2, which shows the subdivision and proposed reference sites in Poland.

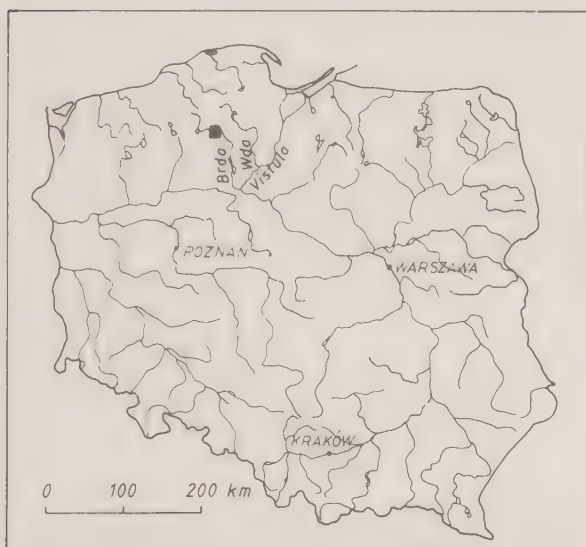
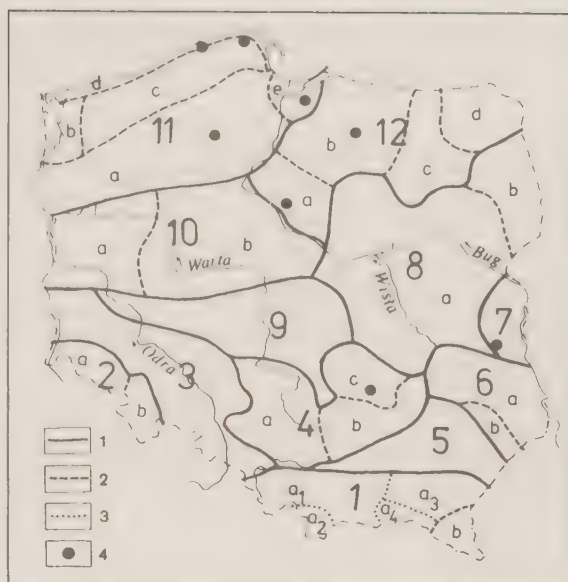


Figure 1. The location of the reference area represented by Lake Wielkie Gacno, (■).

"The type pollen diagrams will show the regional variation in the development of the vegetation and provide a basis for an interpretation of the relation between vegetation, soil and climate development" (Berglund & Digerfeldt 1976). The interpretation of the limnological and environmental development of the reference area, here represented by Lake Wielkie Gacno and its surroundings, is based on chemical and physical analyses. On the basis of several microfossil and chemical analyses, landscape development can be reconstructed and valuable palaeoecological, limnological and hydrological correlations can be made between selected type regions in the temperate zone.

Lake Wielkie Gacno is situated in NW-Poland, in a forested lowland area and fulfils the requirements of a representative lake, when the present and fossil vegetation representation are considered in having a catchment area of radius 15-20 km. This regional representativeness has been tested by analyses of surface pollen spectra from 7 different lakes in the same region compared with one



1. boundaries between the type regions
- 2.-3. boundaries between sub-regions
4. published reference sites

Figure 2. Subdivided palaeoecological type regions and proposed reference sites in Poland (acc. Ralska-Jasiewiczowa in Pawlikowski et al., in print).

lake from an other vegetational area in the same natural geographical area.

The present investigation is also part of a Polish project dealing with the "development, productivity and functional interdependence of typical ecosystems on selected areas of Bory Tucholskie (woodland), of lakelands Iława and Brodnica and of the agricultural Kujawy". This project named R-III-15, is being led by professor dr.hab. Ryszard Bohr, Torun, and most of the research is being performed at the Biological institute of Torun University. This project includes plant- and animal-ecological, hydrobiological and microbiological studies in addition to this present palaeoecological and -limnological investigation and the whole is intended to have practical applications e.g. planning for tourism, industry, urbanization etc. (R-III-15-project, report 1978). In connection with this task, a palaeo-ecological study is invaluable in solving the structure and function of the ecosystem within the landscape.

II. INVESTIGATION AREA

1. Situation, geology, geomorphology, topography and soils

The investigation area is situated in SE Pomerania, in the Bory Tucholskie district. This forest area lies between two tributaries of the Vistula river, the Wda and the Brda. The main lake studied lies between Lake Charzykowskie and the Brda.

The Tucholą pine forest district is situated on the Brzeźna-bridge where Oligocene glauconite sands and Upper Cretaceous marls form the bottom layer. This layer appears in broad erosional cuts in the Miocene sediments. These Miocene sediments, the so-called lignite formation, are a c 80 m thick bed emerging from beneath Pliocene deposits. The deposits sometimes show a sedimentary character due either to glacial or fluvial erosion.

During the last Glaciation, the sub-Quaternary surface achieved its ultimate relief. The thickness of Quaternary deposits in the area is 50-80 m. The composition of Quaternary deposits is shown in Fig. 3. The area around Lake Charzykowskie belongs to the widespread outwash plain in the foreland of the Pomeranian endmoraine zone. The end moraines surrounding the terminal depression of Lake Charzykowskie were probably formed by minor glacial lobes which extended beyond the ice-sheet front. Sometimes they are called Charzykowo-Gwieździn moraines (Pasierbski 1973). The Pomeranian ice-marginal zone is characterized by the close spacing of morainal forms within the main marginal zone and the development of outwash plains (Galon 1961). Numerous extensive depressions have been formed either by meltwater action and melting dead-ice blocks or by the activity of Late-Glacial and Holocene rivers. Shallow kettle holes developed when ice-blocks melted and outwash ice underlaying outwash plains disappeared. Subglacial channels filled with ice became uncovered during 'the Allerød' period in the Brda outwash plains (Kepczyński 1958).

The geomorphology of the investigated area is illustrated in Fig. 4, and the topography in Fig. 5. The largest part of the area N and NE of Lake Charzykowskie is situated between 135 m and 145 m a.s.l. The landscape is characterized by dunes, mostly 140-145 m a.s.l.

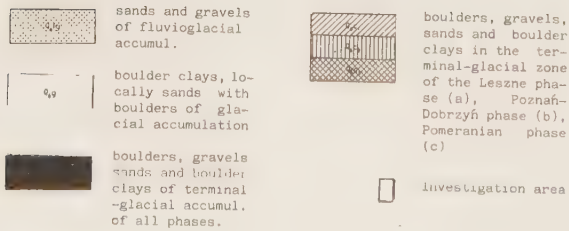


Figure 3. The composition and distribution of the Quaternary deposits in the investigated area (acc. Geological Atlas of Poland, ed. Znosko, J. 1968).

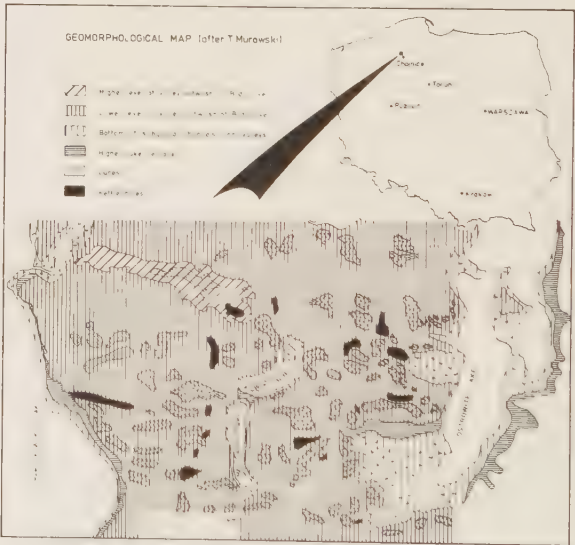


Figure 4. Geomorphology of the investigation area (after T. Murawski, unpubl.).

The dunes are thought to have been formed partly during the cold periods of the Late-Glacial and partly later during the Holocene. According to the several geomorphological investigations from West-Central and North Poland the Late-Glacial dune-forming processes were cyclic in character and dependent on climatic conditions, while those of the Holocene were most probably connected with human activity (Dylikowa 1961; Galon 1961; Kobendzina 1962; Wasylkowa. 1964; Tobolski 1966; Kozarski & Tobolski 1968; Kozarski et al.

1969; Kowalkowski & Borzyszkowski 1977; Kowalkowski 1977, a,b; Kozarski & Rotnicki 1977; Kozarski 1978 a,b; Szczepke et al. 1980).

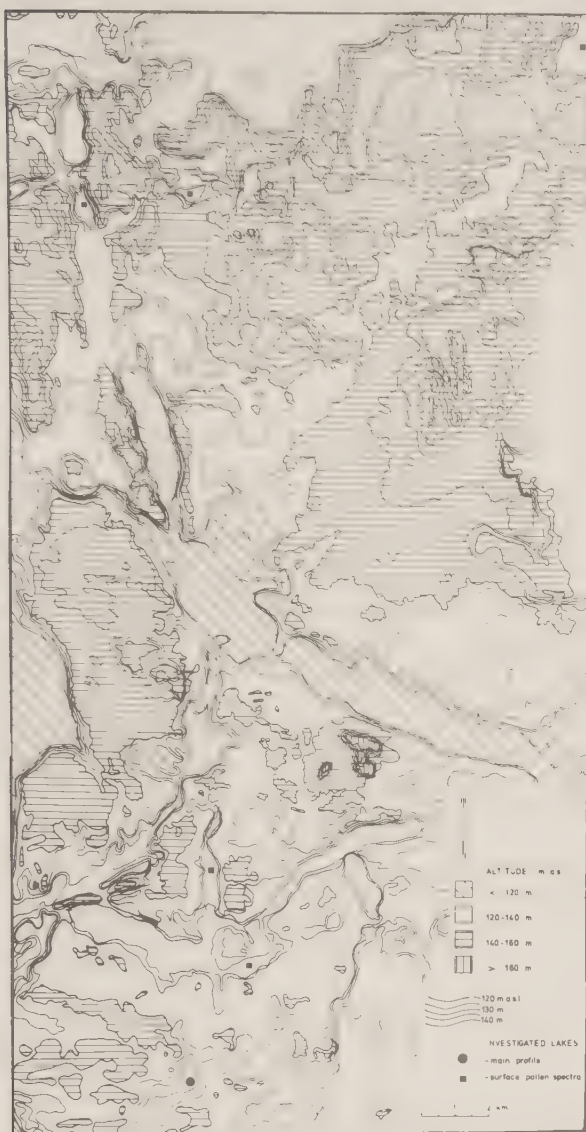


Figure 5. Topography of the investigation area.

The soils originate predominantly in deposits of glacial origin (Kowalkowski & Borzyszkowski 1977). At the present day they are mainly podsoils or podsolized renzinas formed in sands. Because of the leaching of nutrients and the increasing capacity for dissolving nutrients a rapid acidification and impoverishment is going on. The raw humus layer is thin and the illuvial horizon, which is of a rusty colour, is very compact (Medwecka-Kornaś 1966).

2. Climate

The area surrounding Lake Wielkie Gacno belongs to the Lakeland Climate Region (after Romer 1949 in Medwecka-Kornas 1966). The summers are quite cool and the arrival of

spring is delayed due to the great number of lakes. The lakeland climate region lies within an annual isotherm of $+6.5^{\circ}\text{C}$, the mean January temperature is -3°C and that of July $+17.5^{\circ}\text{C}$.

The annual rainfall is ca 600–650 mm and the length of the growing season about 190–200 days (Atlas Klimatyczny Polski IMiGW in Atlas Geograficzny Polski 1978).

The main climatic features of the investigation area are shown in the table 1.

Table 1. Selected climatic data from the Chojnice meteorological station.

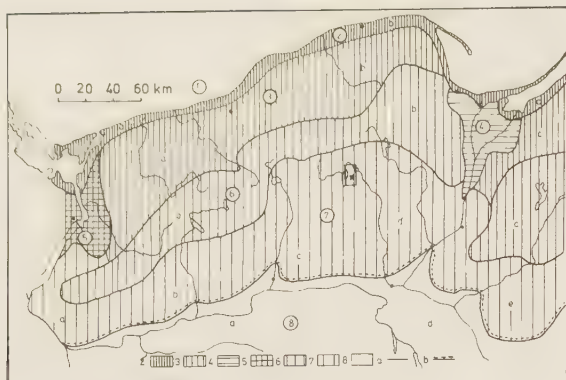
Year	Mean air temperature			Mean annual sum of precipitation, mm
	Jan. $^{\circ}\text{C}$	July $^{\circ}\text{C}$	Year $^{\circ}\text{C}$	
1881–1930	–2.9	16.9	6.6	552
1960	–2.4	16.0	7.2	
1961	–2.6	14.9	7.7	
1963	–9.8	18.2	6.3	
1964	–3.0	17.4	6.8	418
1965	–1.4	14.2	5.7	553
1966	–5.3	19.9	7.0	602
1967	–3.9	17.7	7.7	725
1968	–3.5	15.7	7.4	551
1969				550
1970				820
1971				450
1972				497
1973	–1.6	17.3	7.1	540
1974	3.6	14.4	7.8	678
1975	2.2	18.1	8.2	

3. Phytogeography

The investigation area belongs to the West Pomeranian Transition Belt in the Belt of the Maritime Plains and Pomeranian Uplands which is a part of the Baltic division of the Central European Lowland-Highland Subprovince (Szafer & Pawłowski 1966), (Fig. 6). According to the physiographical division of Galon (1947) the area investigated is a part of the Tuchola forests in the Uplands and basins division (Fig. 7).

The West Pomeranian Transition Belt is characterized by sandy soils and outwash plains with isolated patches of ground moraines. In the north the area is separated from the Pomeranian Lakeland section by a belt of terminal moraines. In the south it slopes towards the belt of the Great Valleys. The rivers Oder and Vistula cut the terminal moraines and form gorges with steep slopes connected with marginal valleys. These azonal gorges have provided migration routes for plants migrating from the south, especially for xerothermic species (Czubiński 1950, Szafer & Zarzycki, eds., 1977).

The majority of the vascular plants in Pomerania are adventitious species not purposely introduced by man (c 70 % of the whole Polish flora). The flora becomes more impoverished towards the east and many species have their limit of occurrence along the Vistula (23.4 % of the flora of Pomerania). The basin between the rivers Brda and Wda, the Tuchola pine forest-district, is one of the most important areas of glacial relicts in the Central European Lowland (0.9 % of species) (Fig. 8).



KINGDOM: HOLOARKTIS

Region: Euro-Siberian

Province: Central European

Subprovince: Lowland-Highland

A. Division: Baltic

A₁. Subdivision: Belt of the Maritime Plains and Pomeranian Uplands

1. Section: Sea

2. Section: Baltic Shore

- a. Western District
- b. Central District
- c. Eastern District

3. Section: Baltic Coast

- a. Western District
- b. Central District
- c. Eastern District

4. Section: Delta of the Vistula

5. Section: Szczecin Lowland

6. Section: Pomeranian Lakeland

- a. District: Wałcz-Drawsko
- b. District: Kartuszy
- c. District: Eldlag-Ostróda

7. Section: West-Pomeranian Transition Belt

- a. District: Lower Odra
- b. District: Verge of the Noteć Proto-Valley
- c. District: Żłotów Upland
- d. District: Tuchola Pinewoods
- e. District: Chełmno-Dobrzyń Upland

A₂. Subdivision: Belt of the Great Valleys

B. Section: Great Poland-Kujawy

- a. District: Noteć
- b. District: Kujawy

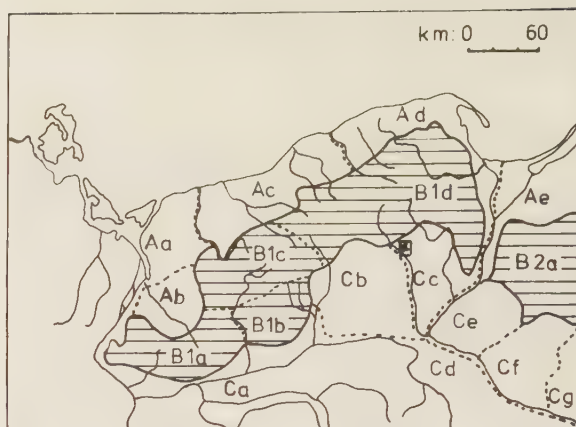
(the map does not include any other districts)

a. Boundaries of sections

b. Boundary of subdivision Investigation area

Figure 6. Geobotanical division of NW-Poland (after Szafer and Pawłowski, 1966)

The main density of steppe elements lies in the area between the endmoraines of the Poznań and Pomeranian stages. Steppe vegetation advanced into Pomerania during the Late-Glacial and early Holocene along the river valleys from refugia in the Vistula basin and Central Germany. About 3.6 % of the species are atlantic, 1.8 % arctic-alpine and finally 2.1 % mountainous species (Czubiński 1950, Szafer & Zarzycki, eds., 1977), (Figs. 8-11).



A. Baltic coastal area:

- a. Szczecin coastal area
- b. Pyrzyce Basin
- c. Słowiński coastal area
- d. Kashubian coastal area
- e. Vistula marshes (Żuławy)
- f. Warmland coastal area

B. Lake districts:

B1. Pomeranian lake-district:

- a. Lake district of Myślibórz
- b. Lake district of Wałcz
- c. Lake district of Drawsko
- e. Lake district of Kartuszy

B2. Masurian lake-district:

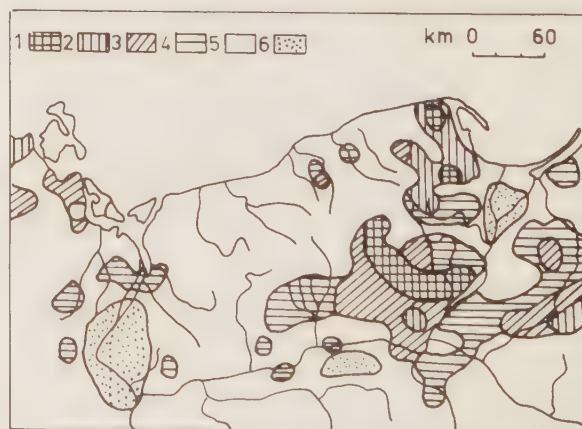
- a. Lake district of Iława

(The map does not include any other districts)

C. Uplands and basins:

- a. Warta-Noteć basin
- b. Żłotów Upland
- c. Tuchola Forests
- d. Toruń-Bydgoszcz basin
- e. Chełmno Upland
- f. Dobrzyń Upland
- g. Plain of Piława

Figure 7. Physiographical division of Pomerania (Galon 1947).



- 1. more than 12 species
- 2. 9-12 species
- 3. 6-9 species
- 4. 3-6 species
- 5. 1-3 species
- 6. lack of cold glacial species

Figure 8. Density of glacial relicts in Pomerania (after Czubiński, 1950).

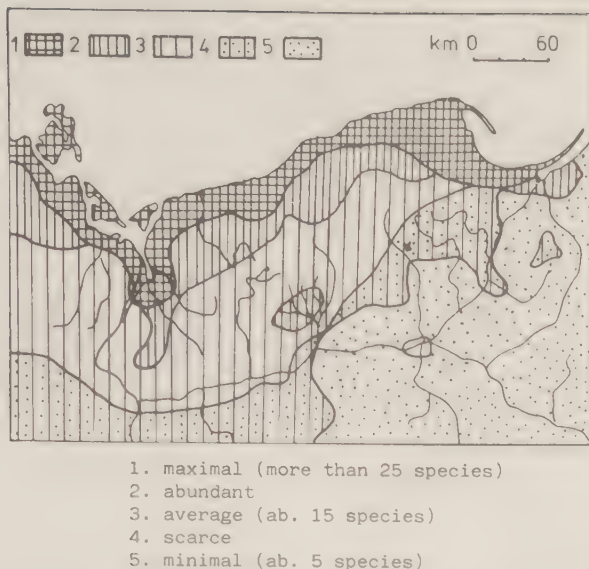


Figure 9. Density of Atlantic species in Pomerania (after Czubiński, 1950)



Figure 10. Density of Mountain species in Pomerania (after Czubiński, 1950).

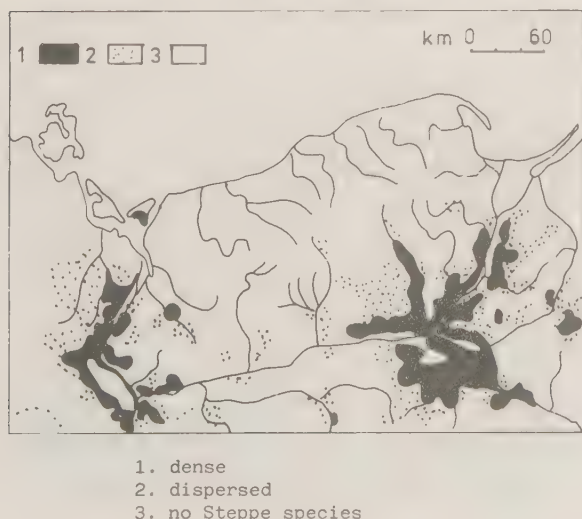


Figure 11. Distribution of Steppe Flora in Pomerania (after Czubiński, 1950).

The dominant forest element is *Pinus* with an admixture of *Fagus* growing mostly on sandy soils. *Pinus*-forests are divided into several associations depending upon the soil moisture: *Vaccinium myrtillus*-, *Vaccinium vitis-idea*-, *Vaccinium uliginosum*-, *Calluna*- and *Cetraria*-types (Szafer & Zarzycki, eds. 1977). On fertile soils *Tilio* - *Carpinetum* (eastern) - and *Galio (silvatici)* - *Carpinetum* (western) - associations are found. *Tilio* - *Carpinetum* is mainly found eastwards from the Wda (Pawłow 1968).

The West Pomeranian Transition Belt is divided into 4 main districts: a. Verge of the Noteć Proto-Valley, b. Żłotów Upland, c. Tuchola Pinewoods and d. Chełmno-Dobrzyń Upland = the eastern side of the Vistula. The investigation area presented is situated in the Tuchola Pinewoods-district.

The pine forests seen today mostly have an anthropogenic origin. The most common associations are *Vaccinio myrtilli*-*Pinetum* (Sokołowski 1965), on wet places *Leucobryo*-*Pinetum* and *Peucedano*-*Pinetum* (Matuszkiewicz & Matuszkiewicz 1973). Besides these the more infrequent *Vaccinio uliginosi*-*Pinetum*, *Luzulo*-*Fagetum* (Matuszkiewicz & Matuszkiewicz 1973) and *Galio (silvatici)*-*Carpinetum* (Sokołowski 1970) are found and sometimes also *Carici elongatae*-*Alnetum* (Sokołowski 1970).

4. Pre-historic and Medieval settlement according to the archaeological evidences

The following outline is based mainly on the investigations of Kostrzewski (1966) and Wiślański (1969) for prehistoric time and Hładyłowicz (1932) and Czubiński (1947) for the historical period. The time-scale given is that generally used by Polish archaeologists for NW-Poland (Jazdzewski 1965; dr. G. Wilke, pers. comm.).

a. The Palaeolithic and Mesolithic (pre 4 200 B.C.)

The first man appeared in Pomerania during the final stage of the Palaeolithic Age and belonged to the hunters who used similar weapons to the people of the Ahrensburg, Lyngby and Swidry cultures. During the Mesolithic hunters of the Tardenoisian culture and fishermen of the Kunda-Maglemose culture are believed to have lived in Pomerania.

b. The Neolithic

Early Neolithic (4 200 - 3 500 B.C.). The first signs of settled life based on cultivation of the land and cattle breeding have been found in the Pyrzyce and Chełmno districts. The peoples belonged to the Danubian I spiral ornamented pottery culture. Settlements were built in the neighbourhood of water, but very rarely on wet or periodically flooded ground. They were concentrated around concave places and did not reach the diluvial plateau. The settlers preferred rich soils so that soils with loose or dry sands, together with all poorly irrigated lands remained empty

or were only sparsely settled.

Middle Neolithic (3 500 - 2 500 B.C.), (Fig. 12 a).

Finds of the Funnel Beaker culture have been made throughout the whole of Pomerania. Objects and settlement remains of the older phase of the Funnel Beaker culture (peasant tribes) have also been found from the whole of Pomerania. Southwards from the Noteć and on the eastern side of the Vistula lived some groups of Danubian II culture (the stroke-ornamented pottery and the Lengyel cultures) as well as the Globular Amphorae culture. There are finds characteristic of the seminomadic pit-comb pottery culture in the coastal area eastwards from the Vistula.

Late Neolithic (2 500 - 1 700 B.C.), (Fig. 12 b).

The major part of Pomerania was occupied by the West Polish group of the Corded Ware culture which can be divided into two groups: The Odra group or Great Poland-Masovia group in the central and southern part of Pomerania, whose people lived by hunting, fishing and cattle breeding, and the Rzucewo group of the coast of the eastern part of Pomerania. The younger phase of the Globular Amphorae and the Funnel Beaker cultures in the southern part of the district around the Vistula remained under the influence of the Corded Ware culture. At the same time a younger group of pit-comb pottery culture was developing in the central, eastern and southern parts of Pomerania.

People of the Funnel Beaker culture often lived in areas beyond those inhabited by the Band Ceramics people, that is mainly in the neighbourhood of valleys, flooded terrain, on peats, marshes, on higher ground, dunes, often near the edge of the diluvial plateau. The character of the settlement types of the Globular Amphorae culture was the same as that of the Funnel Beaker culture, although solid buildings were rarer. The settlements of the Pitted Ware culture were seasonal camps and marsh settlements, while that of the Corded Ware culture is not known.

Neolithic agriculture is believed to have been based on the burning over of small areas of forest. Fields were cultivated around the central settlement. Danubian tribes employed a system of grazing connected with permanent settlements, and the herds were rounded up and led back to the settlement for the night. The Funnel Beaker and Globular Amphorae culture generally used a forest grazing system.

c. Bronze Age

At the beginning of Bronze Age, (Bronze Age I: 1 700 - 1 450 B.C., Fig. 12 c), the greatest part of Pomerania, especially its western and northern part, was under the influence of the Unetice culture. The south-western part, the western area between the Odra and Warta rivers was occupied by people of the Iwno culture, which was a mixture of the Corded Ware and the Bell-Beaker cultures.

Finally, the area around the Vistula and Brda rivers belonged to the Grobia-Smiardowo culture. By about 1 500 B.C. almost the whole of Pomerania was occupied by pre-Lusatian people, only the easternmost parts being populated by the Trzciniec and pre-Baltic cultures, (Bronze Age II: 1 450 - 1 200 B.C., Fig. 12 d).

During the later part of Bronze Age the Lusatian culture spread into Pomerania. This culture is thought to be closely related to the proto-Slavonic culture. The Lusatian culture was divided into several local groups: West-Polish, Pomeranian and Kujavian-Chełmno groups and, later on, West-Great-Polish, East Pomeranian and "Warmia-Masuria" groups, (Bronze Age III: 1 200 - 1 000 B.C. and Bronze Age IV: 1 000 - 650 B.C., Figs. 12 e and f).

On the basis of the finds, one can conclude that at this time the people had commercial connections with Slovakia or Hungary in the south and also with Nordic areas, as well as with the Alpine region. The first lake dwellings appeared in Pomerania.

d. Iron Age

Hallstatt C and D.

The Lusatian culture continued into the first stages of the Iron Age, but it was slowly changing into the Pomeranian culture. In western Pomerania the West-Pomeranian and Górzycze groups were found; in the southern part, Middle Silesian and West Great-Polish groups and in the south west the Chełmno group. In eastern Pomerania, during the Hallstatt C (650 - 500 B.C., Fig. 12 g) the supposed first stage of the Pomeranian culture, the Wielka Wieś (Grossendorf) group appeared, which, during the Hallstatt D (500 - 400 B.C., Fig. 12 h) changed into a separate Eastern Pomeranian culture. This culture expanded rapidly reaching the Rega river in the west and the northern edges of Lower Silesia in the south by the end of the Hallstatt D period.

La Tène (400 B.C. - 0, Figs. 12 i and j).

The Lusatian culture disappeared during the early and middle La Tène, during which time the influence of the eastern Pomeranian culture became stronger. In the middle phase the first Germanic tribes, the Jastorf culture, arrived in western Pomerania. In the late La Tène period the eastern Pomerania culture changed under a strong Celtic influence and appropriated many Celtic forms. This culture is called the Venedian culture. The NW and the northern coastal area formed the Okisywie group and the remaining area belonged to the Przeworsk culture.

Roman period (0 - A.D. 375, Figs. 12 k and l).

At the beginning of the period the Goths appeared in Pomerania and began to populate the barren Kaszubian Plateau. During the older Roman period the Przeworsk group lived in the SW-part and moved into the Chełmno district in the 1st century A.D. and during the younger Roman period moved still further southwards. At this time the greater part of Pomerania was populated by the proto-Slavonic people of the Okisywie group belonging to the Venedic culture.

This group was mixed with Scandinavian immigrants who were probably Gepids and came into Pomerania at the end of 2nd century.

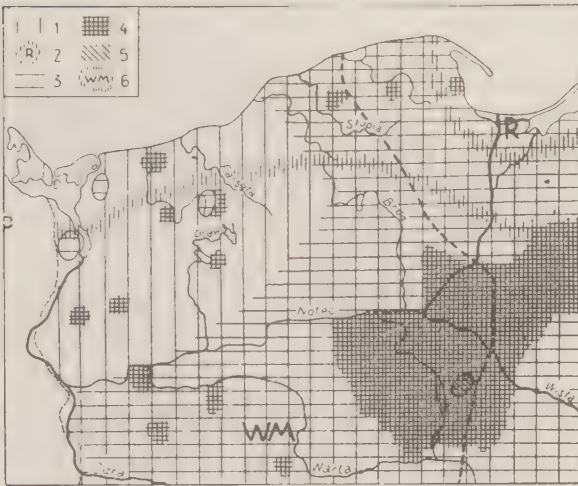
Find from the beginning of the Iron Age indicate Nordic and Eastern Alpine influences. During the La Tène period contacts were established with the Germans and, finally, during the Roman period, with the Roman Empire.



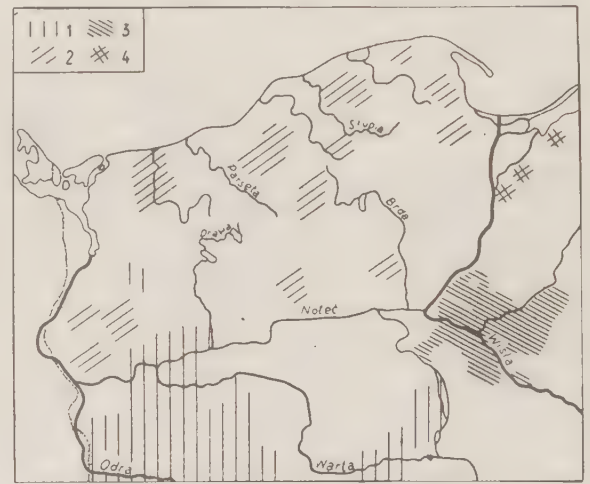
a. Middle Neolithic (3500-2500 B.C.)



d. Bronze Age II (1450-1200 B.C.)



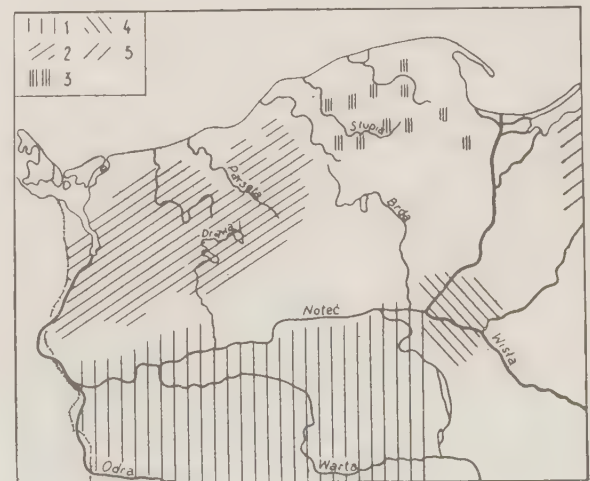
b. Late Neolithic (2500-1700 B.C.)



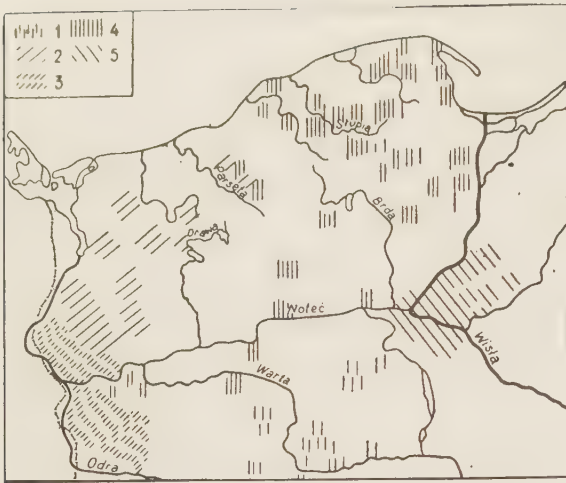
e. Bronze Age III (1200-1000 B.C.)



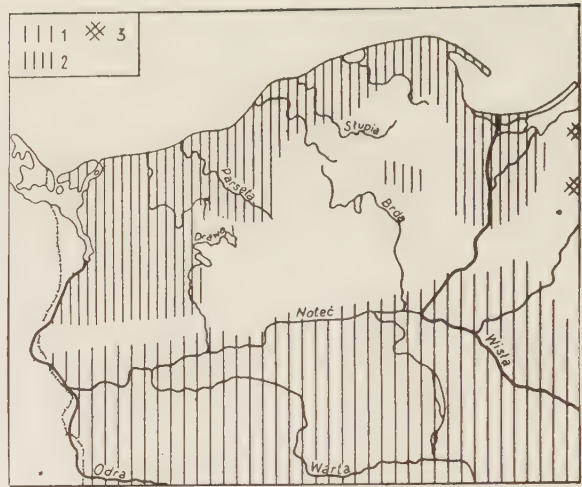
c. Bronze Age I (1700-1450 B.C.)



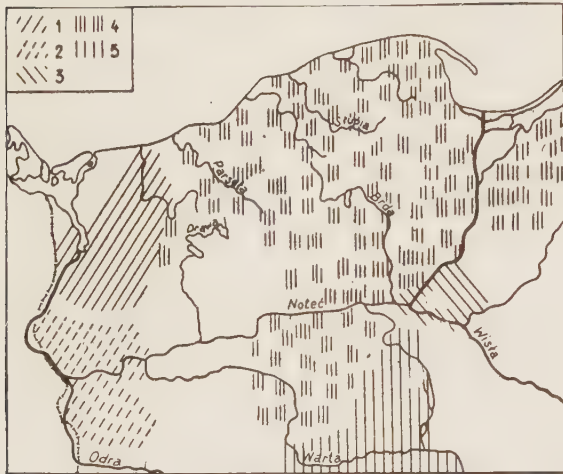
f. Bronze Age IV (1000-650 B.C.)



g. Iron Age I = Hallstatt C (650-500 B.C.)



j. La Tène II (125-0 B.C.)



h. Hallstatt D (500-400 B.C.)



k. Roman (0-A.D. 200)



i. La Tène I (400-125 B.C.)



l. Younger Roman (A.D. 200-375)

Figure 12. The prehistory of Pomerania from the Middle Neolithic until the younger Roman Iron Age (Kostrzewski 1966, modified)

- a. Middle Neolithic (3000-2500 B.C.)
1. The Danubian I culture, 2. The Lengyel culture - group "lazesko-kujawska", 3. The older phase of the Funnel Beaker culture, 4. The Globular Amphorae culture, 5. The Pit-Comb Pottery culture.
- b. Late Neolithic (2500-1700 B.C.)
1. The West Polish group of the Corded Ware culture: divided into two groups: 2. Rzucewo group and 6. Odra = The Great Poland-Masovian group, 3. The younger phase of the Pit-Comb Pottery culture, 4. The younger phase of the Globular Amphorae culture, 5. The younger phase of the Funnel Beaker culture.
- c. Bronze Age I (1700-1450 B.C.)
1.-2. The Unétyce culture, The Iwno culture, 4 The Grobia-Smiardowo culture, 5. The Corded Ware culture, 6. A Baltic group of the Corded Ware culture.
- d. Bronze Age II (1450-1200 B.C.)
1. The pre-Lusatian culture, 2. The Trzciniec culture, 3. A pre-Baltic culture.
- e. Bronze Age III (1200-1000 B.C.)
1.-3. The Lusatian culture (proto-Slavonic): 1 The West-Polish group, 2. The Pomeranian group 3. The Kujawy-Chełmno group, 4. The Baltic culture.
- f. Bronze Age IV (1000-650 B.C.)
1.-5. The Lusatian culture (proto-Slavonic): 1. The west-Great Poland group, 2. The west - Pomeranian group, 3. The east - Pomeranian group The Chełmno group, 5. The Warmia - Masurian group.
- g. Iron Age = Hallstatt C (650-500 B.C.)
1.-5. The Lusatian culture (proto-Slavonic): 1. The middle Silesian and west-Great Poland group 3. The Górzycze group, 4. The east Pomeranian group. 5. The Chełmno group.
- h. Hallstatt D (500-400)
1.-5. The Lusatian culture (proto-Slavonic): 1 The west-Pomeranian group, 2. The Górzycze group, 3. The Chełmno group, 4. The east-Pomeranian group, 5. The east-Great Poland group.
- i. La Tène I (400-125 B.C.)
1.-3. The proto-Slavonic culture: 1. The rest of the Lusatian culture, 2. The east-Pomeranian culture, 3. The Bell-Graves culture, 4. The Germanic Jastorf culture.
- j. La Tène II (125-0 b.c.)
1.-2. The proto-Slavonic culture (the Venedian culture): 1. The Przeworsk group, 2. The Oksywie group, 3. The Baltic culture.
- k. Older Roman Age (0 - A.D. 200)
1.-3. The proto-Slavonic culture (the Venedian culture): 1. The Przeworsk group, 2. The Oksywie group, 3. The distribution of the Oksywie group after A.D. 200.
- l. Younger Roman Age (A.D. 200- A.D. 375)
1.-2. The proto-Slavonic culture (the Venedian culture): 1. The Przeworsk group, The Oksywie group.

e. Migration period

The connections between Pomerania and the Roman Empire weakened considerably. At the same time the majority of proto-Slavonic people left Pomerania and moved to the area between the Odra and Elbe rivers, however, some

groups remained i.e. the Weleti tribes beyond the Odra and the Obodrits in the district later called Mecklenburg.

From the 5th and 6th centuries there are finds of Scandinavian type bearing witness to Nordic tribes.

f. Middle Ages

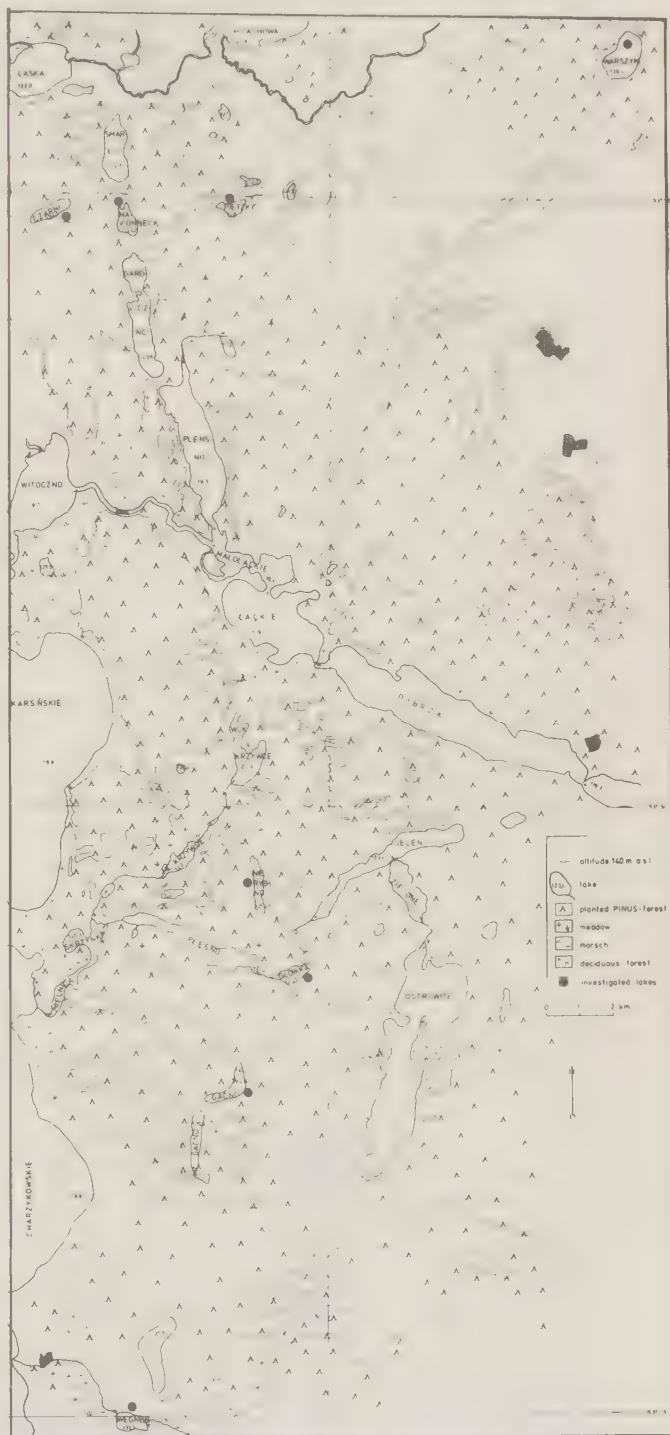


Figure 13. Distribution of vegetation types and soil use in the investigated area (acc. topographic maps, 1:25 000, 702 Rollbick 1975; 2171 Drzewitz, 1938 and 2271 Niesewanz, 1923. Modified).

During the Middle Ages Pomerania was a part of the Polish state. In the beginning it was populated by the Slavonic tribes of Pomerania, and the Chełmno district by the Polish tribes of Kujavians. The oldest Pomeranian fortified camps are from 6th and 7th centuries. The towns at Wolin and Kołobrzeg-Budzistowo are dated to 9th century and at this time there existed Slavonic tribes of Wolinians and Poryczans in Pomerania.

The economy was based on agriculture and cattle breeding. In the 13th and 14th centuries bigger communities and villages began to arise and the fertile soils were tilled as fields. This led to the disappearance of the forests composed of *Quercus* and other broad-leaved trees. On sandy and unfertile soils *Pinus* prevailed, as it does now. On the fertile soils of Kujawy and eastern Great Poland deforestation began most rapidly.

(The distribution of vegetational types and the soil use in the investigated area at the present times is shown in Fig. 13).

5. Outline of previous investigations into the vegetational history

The Tuchola pine forest district has always been a blank area with regard to palynological investigations. However, the lake districts of Kaszubian and Kartuzy to the north of Tuchola has been studied in some detail as has the area to the south of Bory Tucholskie. In the main the studies were done before the second world war and they have proved difficult to obtain.

The only published study from the very district of Bory Tucholskie is that of K. Kepczyński (1958). He presents a pollen diagram from a peat-bog Siwe Bagno. The results are similar to those from Chełmno, Brodnica and Dąbryż. The diagram is zoned according to the system proposed by Nilsson (1948) and comprises data from the "Allerød" to the present. Kepczyński draws the boundary between the Late-Glacial and the Holocene where the *Corylus* curve rises. Slightly afterwards, in the middle of the "Pre-boreal" biozone *Alnus* and *Ulmus* immigrate while *Quercus* appears at the "Pre-boreal"/"Boreal" boundary.

According to Kirkor (1970) *Alnus* appears simultaneously with *Quercus* at the beginning of the "Boreal". Her investigations are from a peat-bog between Asmus and lake Plesno.

The peat-bog, Fletnowo, in the Grudziądz basin between Bory Tucholskie and the lower Vistula valley has been investigated by Kepczyński and Noryskiewicz (1968) both phytosociologically and palynologically. Among the most important works from the Kartuzy area is the investigation of Szafranski (1961). During the whole of the Holocene NAP values are very low, 5-15 %, in this particular peat-bog pollen diagram. Mixed oak forest dominates during the "Atlantic" biozone (zonation according to Firbas 1949) with high frequencies of *Alnus*. In the beginning of the Firbas VIII zone *Betula* increases strongly simultaneously with *Carpinus* and the forest association changes from a mixed oak-forest to the *Querco-Carpinetum* type of forest. At the same level there is clear proof of agricultural activity in the area. During historical times *Fagus* forms pure beech forests, sometimes together with *Quercus* and *Carpinus*. *Pinus* increases dramatically in the uppermost part of the profile.

A. Wodziczko & M. Thomaschewski (1932) demonstrated in the Stanisławskie Błoto peat-bog, in the lake district of Kaszubskie, that there *Carpinus* immigrated from west to east and *Picea* from east to west.

In the Inowrocław district, south of the Tuchola pine forest area, Szafranski (1965) was unable to demonstrate an "Atlantic" biozone (according to Firbas 1949) in a pollen diagram from the Nowiny peat-bog. *Pinus* predominates from the beginning of the "Boreal" biozone to the present. *Quercus* and *Alnus* are found in quite high frequencies, but *Carpinus* and *Fagus* occur only occasionally.

When considering the area directly to the south of the Tuchola pine forest, then this is the only published study. The Wielkopolski national park, however, still further to the south of Tuchola has been well investigated by Szafranski (1973).

The location of the investigations referred to here is shown in Fig. 14.



Figure 14. Location of sites previously investigated by palynological methods in the neighbourhood of Lake Wielkie Gacno.

III. LAKE WIELKIE GACNO

Lake Wielkie Gacno is situated between lakes Charzykowskie and Ostrowite, about 6.5 km north - north-east of the town of Charzykowy. The lake lies 130 m a.s.l. and is surrounded by numerous dunes which rise to an altitude of over 140 m a.s.l.

Because the soils are sandy and unfertile and the landscape is characterized by dunes, the Leucobryo-Pinetum type of forest association is dominant in the surroundings of the lake. This forest association occurs in several variants depending upon the variation in soil moisture and the richness of the soil nutrients. The variants are named after their most common species, namely: Deschampsia caespitosa; Calamagrostis arundinaceae and Pteridium aquilinum; Vaccinium myrtillus; and the moistest one as simply mossy. On the lake shore, where the soils are wet and more fertile the Molinio-Pinetum type of association, sometimes characterized by Ledum palustre can be found. It forms a small belt directly around the lake shore. North-west of Wielkie Gacno the Cladonio-Pinetum association is found on the moister sandy soils. The Vaccinio uliginosi-Pinetum forest association is common in the northernmost parts of Poland on those soils with a rather thick peat layer, but can be found here, too, although only in patches along the southern shore of the lake (the associations acc. Dr. M. Boiński, unpubl.) (Photo 1).

The distribution of the different forest associations in the close vicinity of Lake Wielkie Gacno is shown in Fig. 15.

1. Hydrography

Lake Wielkie Gacno is in part of a glacial channel complex on the lower level of the proto-valley of the Brda river. This glacial channel contains two lakes: MY. Gacno and Wlk. Gacno, both of which are without any in- or outflow. The area of Lake Wielkie Gacno is 13 ha. The greatest water depth exceeds 6 m (Fig. 15) and this is in the north-eastern part of the lake. Mostly water depth ranges between 4 and 5 m. In the south-western part of the lake the water-depth curve runs immediately along the shore with the exception the southern shore. The volume of the lake is c 435 m³.

2. Sediment thickness

Organic fine detritus gyttja covers the bottom throughout the lake. The maximum thickness of Holocene sediments, which is found in the north-eastern part of the lake, reaches 8 m. In the south-western part the thickness is mostly around 5 m. A shelf area, with is mostly around 5 m. A shelf area, with a very thin sediment layer (0.20 - 1.0 m), stick out from the southern shore. It seems that the lake is composed of two basins (Fig. 16).

In the deeper parts the gyttja is underlain by sand and silty sand. At the south-western and north-eastern shores, under the Holocene gyttja, a layer of Late-Glacial age

is found. The thickness of the Late-Glacial sediment reaches 0.70 m.



Symbols for the forest associations (acc. Dr. M. Boiński, unpubl.):

1. Leucobryo-Pinetum
 - a. variant with Deschampsia caespitosa
 - b. variant with Calamagrostis arundinaceae and Pteridium aquilinum
 - c. variant with Vaccinium myrtillus
 - d. mossy variant
2. Molinio-Pinetum
 - a. variant with Ledum palustre
3. Cladonio-Pinetum
 - a. mossy variant
4. Vaccinio uliginosi-Pinetum

Figure 15. Water depth (in m.) of Lake Wlk. Gacno and surrounding vegetation.



Figure 16. The thickness of the Holocene sediments in Lake Wielkie Gacno.

3. Macrophytic vegetation

Lake Wielkie Gacno is a so-called Lobelia lake. In Poland this kind of lake with Lobelia dortmanna and Isoetes communities occurs almost exclusively in Pomerania to the west of the Vistula river (Pawłowski 1966). Due to the oligotrophy of the lake the macrophytic vegetation is only poorly developed. In the littoral zone Lobelia dortmanna, Isoetes echinospora, Carex lasiocarpa, Littorella uniflora, Nitella flexilis and Chara delicatula are found. In the profundal zone the bottom is covered by Drepanocladus fluitans. Along the north-eastern shore there is a reed formed by Phragmites communis, Equisetum and Carex.

4. Limnology

The limnological investigations have been carried out by the Hydrobiological Department of the University of Nicolas Copernicus in Torun.

From the limnological point of view Lake Wielkie Gacno is "untypical". The bottom of the lake is classified as moderately eutrophic and the water as oligotrophic-mesotrophic.

Because the lake is so small and shallow, without any outlet, the profundal zone has the character of the littoral one and the bottom fauna of the whole lake has a littoral character. The hydrobiological data are changing dramatically from one year to the next, which is evidence of an unstable lake. The limnologists believe that even the water will soon become eutrophic (prof. Giziński, pers. comm.).

The contrasting character of the lake water in comparison to the shore vegetation is due to the groundwater flow through the lake (see disc. in Chapt. XII).

The water is slightly alkaline and poor in electrophytes, and the trophic level is low. Some limnological parameters are given in Table 2. The data originates from investigations during the years 1977-1978.

Table 2. Some water parameters of Lake Wlk. Gacno, (acc. prof. dr. Giziński, unpubl.)

1977- 1978	pH	Tempera- ture, °C	O2 mg/l	P2O5 mg/l	Fe () mg/l	Fe-3 mg/l	Cl- mg/l	CaO mg/l	NO2- mg/l	NO3- mg/l	NH4 mg/l
surface											
winter	8.8	1.1	13.8	1.8	0.1	0.1	11	-	-	0.1	0.0
spring	8.4	9.0	9.4	0.2	0.3	0.2	9	80	0.0	0.0	0.1
summer	7.2	20.5	8.5	0.9	0.2	0.1	11	67	0.0	0.0	0.2
autumn	8.0	9.0	-	0.2	0.2	0.1	8.5	70	0.0	-	0.1
bottom											
winter	7.2	4.2	7.9	1.9	0.3	0.3	9	-	0.0	0.0	0.1
spring	7.6	7.8	9.9	0.3	0.3	0.2	7.5	50	0.0	0.1	0.1
summer	7.2	19.5	8.4	0.6	0.4	0.3	8	87	0.0	0.1	0.1
autumn	8.2	9.0	-	0.1	0.3	0.2	8	55	0.0	-	0.1
$\bar{X}$	7.8	10.0	9.6	0.7	0.3	0.2	9	68	0.0	0.0	0.1

IV. METHODS

1. Sampling techniques

Sampling techniques are closely in accordance with those recommended in the project guide for IGCP 158 b (ed. Berglund 1979).

The preliminary stratigraphical investigations of Lake Wielkie Gacno were carried out using a Russian peat sampler of diameter 50 mm and length 100 mm (sampler described by Jowsey 1966). The lake basin was investigated by means of one longitudinal and 5 transverse sections, with particular attention being paid to the shore areas. 12 sediment profiles were taken to the laboratory for more detailed stratigraphical investigations.

A sediment core of eight metres which forms the reference profile was taken from the central north-eastern part of the lake using a Livingstone piston corer with a core diameter of 100 mm and a chamber length of 1.7 m (described by Livingstone 1955, modified corer described by Wright 1967). The loose sediment (0 - 100 cm) was taken with a corer specially designed for sampling surface sediment (described by Digerfeldt & Lettewall 1969). The same method was used when taking the four sediment cores for investigating water level changes.

The sediment cores were transported to the laboratory in tubes and stored in a coolroom. Subsampling was done as soon as possible. The sediment cores were described after extrusion and careful cleaning. The core was prevented from drying out by wrapping it in plastic and samples for the determination of wet density, dry weight and water content, as well as for loss on ignition were taken immediately. Samples for the various different microfossil and sediment chemical analyses were collected every 5 cm and stored in plastic 5 ml containers, 5 from each level. These small air-tight plastic containers were placed

in a larger container, which was then filled with distilled water to prevent possible sediment changes while the samples were stored in the coolroom. The remaining material from the main sediment core was dried at 105°C and stored in a dry place in the laboratory.

The material for investigating recent pollen sedimentation was taken with a Berggren sampler (Berggren 1972) with a tube length of 50 cm and diameter of 70 mm. The surface sediments of 35-10 cm were sampled directly in the field into plastic containers.

The main methods used are shown in table 3.

2. Description of sediments

The sediments will be described in detail in Chapter V. They have been classified according to the characterization system of unconsolidated sediments proposed by Troels-Smith (1955). Element analysis has been used to determine a more precise limit between two sediment types (element analysis, cf. Lundqvist 1927).

3. Laboratory methods

a. Preparation of samples for pollen analysis

The samples for pollen analysis were taken every 5 cm from the Holocene sediments and

Table 3. Working methods used in the investigation of Lake Wielkie Gacno.

Core	Sub-sample (volume/sampling interval)	Analysis
Main profile	1 cm ³ / 5 cm	Pollen percent
	1 cm ³ / 20 cm	Pollen influx
	2-5 mm ³ / 50 cm (at critical points 5-10 cm)	Diatoms
	1 cm ³ / 5 cm	Element analysis
	10 cm ³ / 5 cm	Cladocera analysis
	1 cm ³ / 20-25 cm	Physical sediment analysis
	1 cm ³ / 20-25 cm	Sediment chemical analysis
	1 cm ³ / 20-25 cm	Pigment analysis
	c 350 cm ³ / 50 cm (mainly)	14C-dating
Additional profiles	1 cm ³ / 5 cm	Pollen percent
	c 350 cm ³ / continuous	Pollen influx (only in one of the additional profiles)
	10 cm ³ / 5 cm	Plant macrofossil analysis
		Physical sediment analysis (only in the Late-Glacial part of the WG A1-profile)

every 1-2.5 cm from the Late-Glacial and surface sediments.

All samples were acetolysed and the general treatment follows the method described by Faegri & Iversen (1964). The Late-Glacial sediments, which were rich in minerogenic material were treated by the ZnCl₂-floatation method (Björck et al. 1978).

Absolute pollen determinations were made according to the method described by Stockmarr (1971) by adding 3 Lycopodium tablets, each containing 12 500 spores, to a specific volume (1 cm³) of sediment. Pollen concentration values have been counted according to the formula:

$$\text{Pollen concentration} = \frac{\text{number of spores added in tabl.}}{\text{number of spores counted in prep.}} \times$$

$$\frac{\text{number of fossil pollen grains counted}}{\text{sample volume (cm}^3\text{)}} \times \text{grains} \times \text{cm}^{-3}$$

Pollen influx values (pollen $\times \text{cm}^{-2} \times \text{yr}^{-1}$) have been determined according to the formula:

$$\text{Pollen concentration (grains} \times \text{cm}^{-3}\text{)} \times$$

$$\text{The sediment deposition rate (cm} \times \text{yr}^{-1}\text{)}$$

b. Pollen analyses

All microfossils have been counted using a Zeiss Obton microscope and a magnification $\times 400$, obtained by using $\times 10$ Periplan oculars and a $\times 40$ apochromatic objective (numerical aperture = 0.75). All difficult and important species have been determined using an apochromatic oil-immersion objective ($\times 100$ and numerical aperture = 1.25) or phase contrast equipment.

About 3 000 tree pollen grains have been counted for each level in the main profile. In other analyses, where the main purpose has been to date certain events and correlate these with those in the main profile, the tree pollen sum has been at least 1 000. Throughout, all the pollen spectra are strongly dominated by tree pollen, especially by *Pinus*. Without counting such a large number of pollen many important indicators (cf. human indicators) would not have been recorded.

c. Macrofossil analyses

The investigation of water level changes is based on the macrofossil-analysis of four profiles situated along two transects at right angles to the shore in the northwestern part of the lake. Only one profile from the second transect has been investigated palaeobotanically, however, several sediment profiles were investigated stratigraphically in the laboratory.

Each macrofossil sample comprises 5 cm of the sediment column corresponding to c 350 cm³ in volume. The samples were washed, without any preliminary treatment through a sieve with mesh 0.5 mm. The residue was placed in plastic containers, which were then filled with distilled water. Before removal of the fossils the material was bleached with 3 % oxalic acid.

The fossils were removed under a binocular stereoscope microscope (Nikon SMZ - 2) at magnifications of $\times 10 - 20$ and stored in plastic containers filled with a glycerine-alcohol mixture (glycerine: 96 % alcohol: distilled water, in the proportions 1:1:1 with added thymol).

After the fossils had been removed the dry weight of the residue and the amount of minerogenic material contained within it were determined. (In the diagram the blocked-in curve = residue after ignition at 550°C, mg/350 cm³ and the open curve = dry weight mg/350 cm³).

d. Diatom analyses

In order to solve the palaeolimnological problems, diatom analyses were undertaken from the main Wielkie Gacno sediment core with a sampling interval of 20 cms.

The samples were all prepared and analysed by Mrs. Hannelore Håkansson. They were extremely rich in both *Cladocera* remains and *Pinus* pollen grains, which gave a deal of trouble in preparing the samples.

The preparation procedure was as follows:

1. The samples were heated in HCL (10 %) and washed with H₂O.
2. The samples were heated in H₂O₂ (30 %) at a temperature of 60°C for about 30 mins and washed with H₂O. This was repeated at least 3 times.

After this commonly used preparation method the *Cladocera* remains and the *Pinus* pollen grains were still intermixed with the diatom valves, forming thick chunks. Preparation was therefore continued using the modified van der Werff (1955)-method:

3. The samples were heated in H₂O₂ (30 %) mixed with H₂SO₄. After they had been allowed to cool samples were washed with H₂O.
4. The samples were treated KMnO₄.
5. The samples were treated with oxalis acid and washed several times with H₂O.

Clophen harz (R.I. = 1.66) was used as a mounting medium. Analyses were carried out using a magnification of $\times 1000$ and phase contrast equipment. At least 300 valves were counted on each level.

e. Chemical analysis

Samples for chemical analysis were taken every 20 - 25 cm from the main Wielkie Gacno sediment core.

Wet density was determined by weighing 10 cm³ sediment at 20°C. Dry weight and water content were determined after drying to constant weight at 105°C, loss on ignition after ashing at 550°C.

Na, K, Ca, Mg, Fe and Mn were determined by atomic absorption spectrophotometry after digestion with conc. HNO₃ and HClO₄ (4:1 v/v).

Organic carbon was determined according to Tyurin's method described in Kononova (1961).

Nitrogen was determined on dried sediment according to the Kjeldahl method.

Phosphorus was analyzed according to

the vanadine method described in Kitson & Mellon (1944).

f. Pigment analysis

Samples for pigment analysis were taken from the same levels as those for chemical analysis. They were prepared and analysed according to the recommendations in the IGCP project guide (Bengtsson 1979).

g. Other analyses

All physical analysis were carried immediately the sediment core was cleaned. Samples of 10 ccl for determining wet density, dry weight and water content as well as loss on ignition were taken every 5 cms, weighed and dried at 105°C for c. 24 hours and weighed again. This determined the dry weight and water content. The samples were then ignited at 550°C and then weighed again. The loss on ignition is expressed as the weight loss after ignition as a percentage of dry weight.

The origin and development of Lake Wielkie Gacno has also been studied by means of Cladocera analysis of the bottom deposits of the lake. The material for the Cladocera analyses was taken from the main sediment core at every 5 cm.

These investigation were undertaken by prof. dr. hab J. Mikulski of the Dep. of Hydrobiology, University of Nicolas Copernicus (Torun, Poland), and the results will be published separately by him.

Element analyses were carried out according to the method proposed by Lundqvist (1926) (see also Berglund 1979a) for a precise determination of the composition of sediments. The analyses proved necessary, especially at those points where the sediment changes from algal gyttja to detritus gyttja.

h. A remark on charcoal analyses

Charcoal analyses are often used, particularly in connection with investigation involving human impact (e.g. M. Tolonen 1978, Huttunen 1980). This investigation does not include such analyses for the simple reason that there were no charcoal particles in the sediment.

4. Identification

a. Pollen and spore identification

Pollen grains and spores were determined using the main key published by Faegri & Iversen (1964) and the general works of Erdtman et al. (1961) and Moore & Webb (1978). For critical identifications comparisons were made with three reference collections, prepared by the author from the material collected in Finland, Northern Sweden and Switzerland and each containing 700 - 1000 different species, as well as with the pollen reference collection of the Quaternary Laboratory of the University of Lund.

In addition to these several special keys have been used, e.g.:

Betulaceae, the identification of Betula nana from the other Betula species: Usinger (1975 and litt. cit. therein).
Caryophyllaceae: Andersen (1961), Chanda (1962), Fredskild (1967), Birks (1973).
Compositae tubuliflorae: Stix (1969), Dimon (1971), Birks (1973).
Gramineae, Cerealea: Beug (1961), Andersen & Bertelsen (1971).
Lycopodiaceae: Moe (1974).
Plantaginaceae: Andersen (1961), Birks (1973).
Primulaceae: Punt (ed.) (1976).
Polypodiaceae: Sorsa (1964).

Identification of the pollen and spores has been attempted to the lowest possible taxonomic level and particular attention has been paid to the identification of species indicating human impact, but in many cases the author has had to be content with the level of family (c.f. Cruciferae, Umbelliferae).

b. Macrofossil determination

The main purpose of the macrofossil analyses was the interpretation of the water-level changes and so quite a large meshed sieve was used for washing the samples, since it has been shown that with a mesh of 0.5 mm most seeds and fruits of interest for such an interpretation will be retained (Digerfeldt 1979).

On the whole seeds and fruits were found in only small quantities because of the oligotrophy of the lake.

In identifying the fossils, macrofossil photographs and drawings in a variety of works have been in valuable (Wasylikowa 1979 and litt. cit. therein). Of importance are the Atlases of Bertsch (1941), Beijerinck (1947), Nilsson & Hjelmqvist (1967), Berggren (1969), Kats et al. (1965, 1977).

Reference material in the collections of the Dept. of Quaternary Geology in Lund has also been of great help.

c. Diatom identification

Identification presented many problems because some species occurred in all possible morphological variations. Several critical cases have been photographed under both the SEM and the light microscope. In addition to many special publications, general identification floras and atlases were used, including: Brockmann (1914, 1954), Cleve-Euler (1951-1955), Florin (1970), Foged (1964, 1965, 1968, 1969, 1977, 1978), Hendey (1947), Hustedt (1927, 1930, 1938, 1939, 1957), Mölder & Tynni (1967-1973), Patric & Reimer (1966), Peragallo, Smith (1874-1959), Simonssen (1962) and Werff, van der (1958-1974).

5. Presentation of results and the base of calculations

a. Pollen diagrams

The pollen diagrams are constructed in the same way as suggested in the IGCP-guide (c.f. Berglund 1979). The main pollen diagram

and the correlation pollen diagrams from those cores used for the macrofossil analyses have a uniform format. The pollen analyses of the macrofossil cores complement the results of the main pollen diagram and have often proved most valuable when interpreting and reconstructing the local and regional vegetation history. Therefore these diagrams are, contrary the usual practice, drawn in as much detail as the main pollen diagram.

On the extreme left of the diagram pollen concentration, if available, is given. Then follows a column for uncorrected radiocarbon dates (B.P.), as well as one for corrected ones. This follows the recommendations in the IGCP-guide. Corrections have been made according to a graphically constructed time-depth diagram (Fig. 19 and Table 5). However, a column with an estimated time-scale has not been included. Depth (cm) below the water surface or soil surface is indicated at the side of the lithology column in which the sediment type is depicted in the symbols proposed by Troels-Smith (1955).

Those levels analysed for pollen and spores are shown by numbers and horizontal lines, while in the final column to the left of the pollen curves the core segments are illustrated.

The pollen diagram is divided into the following parts:

Diagram A. This diagram comprises all terriphytic spermatophytes which are grouped according to their main life forms and presented in the order of immigration. Calculations are based on a total pollen sum of AP + NAP terriphytic spermatophytes without any reductions.

A1: A cumulative area diagram showing the proportions between

a. trees and forest shrubs: Betula, excl. B.nana, Pinus, Alnus, Corylus, Ulmus, Quercus, Tilia, Fraxinus, Acer, Fagus, Carpinus, Picea, Populus, Sorbus, Salix, Viburnum, Hedera, Viscum. The curves for Betula, Pinus and Quercetum Mixtum (= Ulmus, Quercus, Tilia, Fraxinus, Acer) have been drawn within this area of the diagram.

b. Shrubs: Hippophaë, Juniperus.

c. Dwarf-shrubs: Betula nana, Calluna, Eri-caceae undiff. and Empetrum and

d. Herbs and graminids excl. limnophytes, telmatophytes and amphiphytes.

A2: Silhouette curves for important terriphytic spermatophytes. The shaded curves indicate actual percentages relating to the scales at the top of the diagram and the unshaded ones % values. The minimum value for %-curves is 1.0 %. The groups are the same as in A1. Herbs and graminids are presented in the following order:

1. Plants, which cannot be placed into any definite ecological group: Gramineae, Cyperaceae, Ranunculus undiff., Compositae liguliflorae, Compositae tubuliflorae undiff., Galium Labiatae undiff. and Thalictrum.

2. Poly- and mesohygrobic terriphytes (c.f. Iversen 1936): Filipendula, Potentilla, Umbelliferae, Aster, Labiatae undiff.

3. Arctic-alpine tundra elements and forest plants as well as species not influenced by man: Anemone, Melampyrum, Mercurialis, Heli-anthemum, Dryas, Saxifraga.

4. Apophyte species (c.f. Linkola 1916, Ahti & Hämet-Ahti 1971): Plantago major, Rumex acetosella coll., Artemisia, Chenopodiaceae, Caryophyllaceae, Achillea-type, Senecio-type, Papaveraceae, Prunella-type, Urtica.

5. Anthropochor species (c.f. Linkola 1916, Ahti & Hämet-Ahti 1971): Plantago lanceolata, Cerealia, Centaurea cyanus, Fagopyrum, Cannabaceae.

Species which occur sporadically or have only very low frequencies are placed in a separate column, Varia, where the names and percentages are given for these species.

Sometimes it has been difficult to group species which have a wide ecological tolerance or families which include a large number of species indicating different ecological situations (c.f. Cruciferae, Caryophyllaceae, Cannabaceae, Umbelliferae, Filipendula).

The last two columns in this part of the pollen diagram show the pollen sum of terrestrial spermatophytes and the number of pollen sum of terrestrial spermatophytes and the number of pollen types in this pollen sum.

The second part of the diagram (Diagram B) comprises the silhouette curves of Pteridophytes. The diagram is composed of the most common species in this group: Polypodiaceae undiff. (incl. Polypodium vulgare, Lastrea dryopteris), Lycopodium undiff. (incl. Lycopodium annotinum, L.complanatum, L.clavatum), Pteridium and Equisetum.

Limnophytes (c.f. Iversen 1936) are illustrated in Diagram C. The silhouette curves of the most common limnophytes (Isoetes, Lobelia, Myriophyllum, Potamogeton, Nymphaea) are followed by a summation curve for all those limnic spermatophytes recorded.

Diagram D contains silhouette curves of telmatophytes and amphiphytes (c.f. Iversen 1936) followed by a summation curve. In most cases the frequencies of Sparganium and Typha latifolia were so high that they have been drawn.

Sphagnum was recorded only sporadically but nevertheless it has been indicated in Diagram E.

Pediastrum colonies are illustrated in Diagram G.

The percentages of particular taxa within the groups B-G have been calculated on the basis of the basic sum (C terrestrial spermatophytes) + the pollen sum of the species in question.

Special pollen diagrams

Survey pollen diagram for interpretation of the human impact

In the discussion of human impact a simplified pollen diagram has been used. This diagram, in the main, follows the model originally used by Berglund (1969). The base of the calculations is the total sum of terrestrial spermatophytes without any corrections.

Selected species are presented in six main ecological groups:

a. Trees of rather moist soils: Alnus.

b. Highly competitive and shade-tolerant trees: Ulmus, Tilia, Fraxinus, Quercus.

c. Trees of the same ecological group but which have immigrated during the late Holocene: Fagus, Carpinus and Picea.

d. Poorly competitive and light-demanding trees: Corylus, Pinus and Betula.

e. Apophytes, both shrubs, herbs and graminids favoured by man: Juniperus, Calluna, Gramineae, Cannabaceae, Plantago major, Artemisia, Pteridium and Rumex acetosella coll.

f. Anthropochores; herbs and graminids introduced by man: Plantago lanceolata, Cerealea.

The diagram also has columns for radiocarbon dates (uncorrected radiocarbon years B.P.), for chronozones (c.f. Mangerud et al. 1974) and for the archaeological time-scale, which has been plotted against a corrected radiocarbon time-scale.

Stages of human expansion are indicated in a specific column.

Pollen influx diagram

After the sediment accumulation rates were calculated pollen influx diagrams were constructed in a manner similar to that of the percentage diagrams. Only the most important pollen and spore types are drawn and their subdivision and order follows the same pattern as that applied to the percentage diagrams.

Survey AP-diagram

In connection with the discussion on the regional vegetational development and the human impact on the natural vegetation, a tree pollen diagram is presented from the main sediment core with corrected pollen values.

These corrections have been calculated according to the results of Andersen (1970, 1973) on the relation between present-day pollen deposition and vegetation. He found that, in Denmark, the pollen grains of some tree species appear to be over-represented in the general pollen rain while other species produce a smaller number pollen grains than would be expected from the number of individual trees present. In order to obtain more reliable values for the AP-grains the following calculations have been made:

- the total number of pollen grains of each of Pinus, Betula, Alnus, Corylus and Quercus found in each analysis divided by 4,
- those of Carpinus, divided by 3,
- those of Ulmus and Picea, divided by 2,
- those of Tilia and Fraxinus, multiplied by 2,
- those of Fagus are left unchanged.

The basis for the percentage calculations is the total number of corrected AP.

In the diagram, the order of species is the same as in the main pollen diagram, and there are also columns for the pollen assemblage zones 14C-dates (uncorrected and corrected radiocarbon years B.P.) and for chronozones (cf. Mangerud et al. 1974).

Survey diagram for human impact

The different anthropogenous phases can be clearly seen in the human impact diagram, where the total sum of the pollen grains of anthropochores and apophytes are plotted symmetrically from a vertical axis. In this diagram the relationship between the human indicator and Cerealea pollen grains and the archaeological periods is clearly seen.

The human indicators are taken here as Artemisia, Rumex, Chenopodiaceae, Achillea-type, Caryophyllaceae, Leguminosae, Prunella-type, Plantago lanceolata, Polygonaceae, Senecio-type, Plantago major, Centaurea cyanus and Fagopyrum. The percentage values of Cerealea are separated and drawn nearest to the vertical axis. The basis for the percentage calculations is the total sum of terrestrial spermatophytes without any corrections. The local anthropogenous phases, corrected 14C-age, archaeological periods and chronozones are also shown in the diagram.

b. Macrofossil diagrams

The frequencies of seeds, fruits and other macrofossils are representing the diagrams in absolute numbers per 350 cm³ sediment. Following the columns for depth (cm) below surface and sample number, are the curves for loss on ignition and for the amount of minerogenic material in the residue after washing. These columns, which are all at the left hand side are then followed by the

silhouette curves of limnophytes, telmatophytes and amphiphytes, terrestrial spermatophytes and other macrofossils respectively.

To the right of the diagram the depth below surface is repeated, followed by the pollen assemblage zones.

c. Diatoms

The means of illustrating the results of the diatom counts is analogous to that of pollen analysis, in which the numbers of individuals of each taxon are expressed as a percentage of a total sum (100 %). The numbers of valves of Tabellaria and Fragillaria have been excluded from the total sum.

6. Zoning of the pollen diagrams

In order to facilitate the description of the pollen diagrams they have been divided into pollen assemblage zones. The available Polish pollen diagrams are poor in radiocarbon datings and therefore some division has also been necessary in order to compare the different regions with the Wielkie Gacno - area. By means of radiocarbon datings from the sediment studied here it has been possible to arrive at an absolute chronology for the zone boundaries and also to correlate the profile studied with those from more distant regions for which a radiocarbon time-scale is also available.

Pollen assemblage zones in their present sense have been defined as biostratigraphical units by many authors (e.g. Cushing 1967, West 1970, Birks 1973). The system has been applied in America by Cushing (1967) who fixed the zone boundaries according to the Code of Stratigraphic Nomenclature of American Nomenclature (1961): "An assemblage zone is a body of strata characterized by a certain assemblage of fossils without to their ranges; it receives its name from one or more of these fossils."

The assemblage zones and their names are intended to demonstrate the immigration and succession of trees as reflected in the pollen flora. The zones do not carry any ecological or climatic implications, although the sequence of immigration may be the reflection of a climatic change which had started somewhat earlier. West (1970) has emphasized that "the pollen assemblage zone reflects a vegetation unit or collection of units of local and/or regional significance".

Birks (1973) defined his assemblage zone as "a body of sediment with a consistent and homogenous fossil adjacent sediment bodies by differences in the kind and frequencies of its contained fossil pollen grains and spores". His definition is in accordance with that for an assemblage zone in The International Guide to Stratigraphic Classification (Hedberg 1972).

The most objective way of drawing the boundaries of pollen assemblage zones today is to employ numerical methods, where the definition is then on the basis of specified mathematical criteria (e.g. Birks & Berglund 1979).

In this paper, the conventional zoning is more or less confirmed by the numerical methods. Here the pollen assemblage zones are defined in the conventional way, on the basis of observations of the pollen and spore

content of the sediments, without any reference to climate, sediment or chronology. The pollen assemblage zones are subdivided into pollen assemblage subzones, and zones are named after terriphytic spermatophyte pollen grains. The order of the pollen types in the name indicates the supposed significance of the species during the corresponding period. Every p.a.z. has been given an abbreviation of WG (in macrofossil diagrams the abbreviation corresponds to that of the profile in question) followed by a number which indicates the position of the zone, starting from the bottom of the profile.

Later on in this study all the pollen assemblage zones have been related to the absolute chronology, put in a table and compared with the chronozones (c.f. Mangerud et al. 1974).

7. Radiocarbon analysis

25 samples were submitted to the Radiocarbon Dating Laboratory in Lund. 19 of these were collected from the main profile, covering the Holocene period. The Late-Glacial phase has been dated from the WG A1-profile on the basis of four samples. One sample comprises a part of a dugout canoe recovered from the bottom of Lake Wielkie Gacno. The samples consisted of a 5 cm thick sediment sequence from a 100 mm diameter Livingstone core. They were dried at 105°C before submission and pretreated with HCl at the Radiocarbon Dating Laboratory.

The calculation of the radiocarbon age is based on a half-life of 5568 years for ^{14}C . The results are given in the number of years before 1950.

The dates are also published in the official dating lists of the laboratory (Håkansson 1980).

8. Determination of the rate of sediment accumulation

The ^{14}C dates are used to give a radiocarbon time-scale to the diagram and allow the determination of the rate of sediment accumulation, necessary for the calculation of pollen influx values and for the calculation and interpretation of the chemical analyses.

The rate of accumulation is illustrated in the diagrams by a curve. The available ^{14}C dates are plotted against the depth below the sediment surface and a time-depth curve is fitted graphically to the data.

V. STRATIGRAPHY OF LAKE WIELKIE GACNO

The sediments are described according to the characterization system of unconsolidated sediments proposed by Troels-Smith (1955).

The location of the profiles described below is shown in Fig. 17.

In the preliminary stratigraphical investigations only the thickness of the minerogenic and organogenic material (thought to be Late-Glacial and Holocene sediment respectively) was recorded, (Photo 2.).

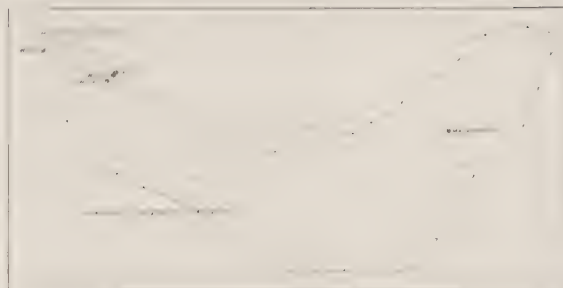


Figure 17. Map showing the situation of the investigated profiles. The situation of the points of the preliminary stratigraphical investigation is marked by X.

Main profile Wielkie Gacno

Depth below water surface, cm (water depth 505 cm)	Layer no.	Description of sediment
505 - 890	1	Fine detritus gyttja, dark-brown. Composition: Ld° 4, Dg + Lower boundary diffuse.
890 - 1055	2	Algal gyttja, dark brown. Composition, Ld° 2, Ld (algae) 2. Lower boundary diffuse.
1055 - 1305	3	Algal gyttja, dark brown. Composition, Ld° 1, Ld (algae) 3. Lower boundary sharp.
1305 - 1315	4	Silty sand, light bluish-grey. Composition: Ag 2, (Ga+Gs) 2.

Wielkie Gacno A1

Depth below surface, cm (not-analysed Sphagnum-peat 150 cm, water 20 cm)	Layer no.	Description of sediment
170 - 245	1	Detritus gyttja, containing, in the upper part, some fine rootlets and rhizomes of <u>Sphagnum</u> and aquatic plants, <u>Equisetum</u> and <u>Phragmites</u> , brown. Composition: upper part: Dh1, Dg1, Ld°2; lower part: Dh+, Dg2, Ld°2. Lower boundary diffuse.
245 - 270	2	Fine detritus gyttja, brown. Composition: Ld°4, Dg+ Lower boundary diffuse.
270 - 323	3	Algal gyttja with numerous wood pieces especially in the lower part, dark brown. Composition: Ld°1, Ld (Algae)2, D11. Lower boundary sharp.
323 - 334	4	Clayey algal gyttja, greenish-brown. Composition: Ld°2, Ld (Algae)1, (As+Ag)1. Lower boundary diffuse.
334 - 353	5	Clay gyttja, some admixture of sand grains in the lower part. Dark greenish-grey, turning into light greenish-grey downwards. Composition: upper part: Ld°2, (As+Ag)2; lower part: Ld°2, (As+Ag)2, (Ga+Gs)+ Lower boundary sharp.

353 - 355	6	Silty sand, bluish-grey. Composition: Ag2, (Ga+Gs)2 Lower boundary sharp.
355 - 363	7	Clayey algal gyttja, dark greenish-brown. Composition: Ld°2, Ld (Algae)1, (As+Ag)1 Lower boundary sharp.
363 - 372	8	Algal gyttja, dark brown, almost black. Composition: Ld°1, Ld (Algae)4 Lower boundary sharp.
372 -	9	Silty sand, bluish-grey. Composition: Ag2, (Ga+Gs)2

Wielkie Gacno A2

Depth below surface, cm, (not-analysed Sphagnum-peat 100 cm, water 60 cm)	Layer no.	Description of sediment
160 - 305	1	Detritus gyttja, dark brown. Composition: Dh+, Dg2, Ld°2 Lower boundary diffuse.
305 - 381	2	Algal gyttja, dark brown. Composition: Ld°2, Ld (Algae)2 Lower boundary diffuse.
381 - 389	3	Clayey algal gyttja, light brown. Composition: Ld°2, Ld (Algae)1, (As+Ag)1 Lower boundary diffuse.
389 - 407	4	Clayey algal gyttja, dark greenish-brown. Composition, Ld°1, Ld (Algae)2, (As+Ag)1 Lower boundary sharp.
407 - 410	5	Silty clay, light bluish-grey. Composition: (As+Ag)3, (Ga+Gs)1 Lower boundary sharp.
410 - 423	6	Clayey algal gyttja with an admixture of sand and silt, light greenish-brown. Composition: Ld°2, Ld (Algae)1, (As+Ag)1, (Ga+Gs)+ Lower boundary sharp.
423 - 426	7	Silty sand, light grey. Composition: Ag2, (Ga+Gs)2 Lower boundary sharp.
426 - 431	8	Clayey algal gyttja, dark grown. Composition, Ld°2, Ld (Algae)1 Lower boundary sharp.
431 - 436	9	Algal gyttja, dark brown-black. Composition: Ld°+, Ld (Algae)4 Lower boundary sharp.
436 - 443	10	Silty, sandy algal gyttja, light greenish brown. Composition, Ld°2, Ld (Algae)1, (Ga+Gs)1 Lower boundary sharp.
443 -	11	Silty sand, bluish-grey. Composition: AG2, (Ga+Gs)2

Wielkie Gacno A3

Depth below water surface, cm (water depth 160 cm)	Layer no.	Description of sediment
160 - 490	1	Fine detritus gyttja, dark brown. Composition: Ld°4, Dg+ Lower limit diffuse.



Photo 1.a. The surroundings of Lake Wielkie Gacno is characterized by dunes and the dominant forest association type is Leucopryo-Pinetum.



Photo 2.a. Field work in oktober 1977.

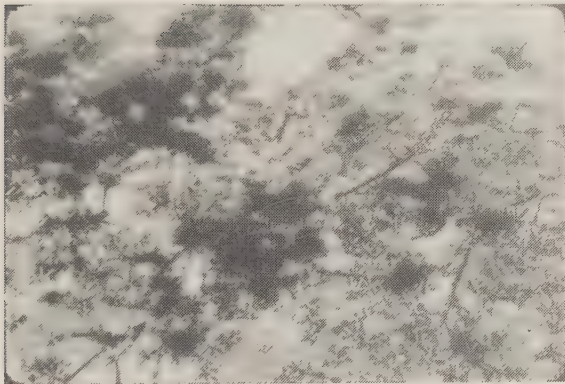


Photo 1.b. Lobelia dortmanna and Isoetes communities on the bottom of Lake Włk Gacno.

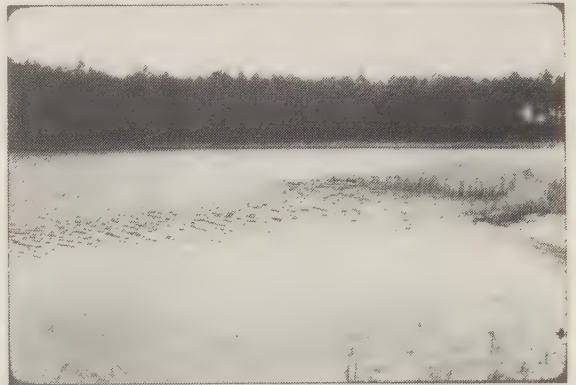


Photo 2.b. The shallower north-eastern part of the lake.

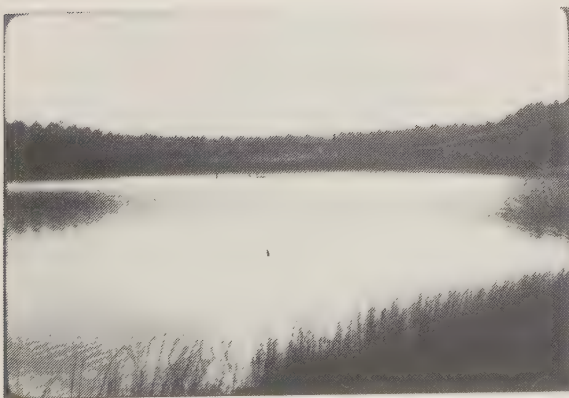


Photo 1.c. Along the shore there are growing Phragmites communis, Equisetum and Carex. On the back-ground the location of the main profile.



Photo 2.c. Location of additional profiles A1, A2, A3.

(Photo: B.E.Berglund, 10-1977)

490 - 540	2	Algal gyttja, dark brown. Composition, Ld°2, Ld (Algae)2 Lower limit sharp.
540 - 567	3	Algal gyttja, dark brown-black. Composition: Ld°1, Ld (Algae)3 Lower limit diffuse.
567 - 574	4	Algal gyttja with abundant plant remains, mainly rhizomes, dark black-brown. Composition: Ld°1, Ld (Algae)2, Dgl, Dh+ Lower boundary sharp.
574 - 586	5	Algal gyttja with admixture of clay, brown. Composition, Ld°1, Ld (Algae)2, (As+Ag)1 Lower boundary sharp.
586 - 595	6	Algal gyttja with abundant plant remains mainly rhizomes, dark black-brown. Composition: Ld°1, Ld (Algae)2, Dgl, Dh+ Lower boundary diffuse.
595 - 600	7	Clayey algal gyttja with plant remains, roots and rhizomes, greenish-brown. Composition: Ld°2, Ld (Algae)1, (As+Ag)1, Dg+ Lower boundary sharp.
600 - 607	8	Clayey algal gyttja, greenish-brown. Composition: Ld°2, Ld (Algae)1, (As+Ag)1 Lower boundary diffuse.
607 - 626	9	Clayey algal gyttja with some sand grains in the lower part, greenish-brown turning into light greenish-brown. Composition: Ld°2, Ld (Algae)1, (As+Ag)1, (Ga+Gs)+ Lower boundary sharp.
626 - 632	10	Silty sand, bluish-grey. Composition, Ag2, (Ga+Gs)2 Lower boundary sharp.
632 - 644	11	Sandy, silty algal gyttja, greenish-grey. Composition: Ld°2, Ld (Algae)1, (Ga+Gs)1 Lower boundary sharp.
644 - 654		Algal gyttja, dark black-brown. Composition: Ld°+, Ld (Algae)4 Lower boundary sharp.

Wielkie Gacno B

Depth below surface, (not-analysed <u>Sphagnum</u> -peat 190 cm, water 130 cm)	Layer no.	Description of sediments
320 - 525	1	Fine detritus gyttja, brown. Composition: Ld°4, Dg+ Lower boundary diffuse.
525 - 657	2	Algal gyttja, dark brown. Composition, Ld°1, Ld (Algae)3 Lower boundary diffuse.
657 - 691	3	Algal gyttja with some clay especially in the lower part, brown. Composition: Upper part: Ld°2, Ld (Algae)2, (As+Ag)+; Lower part: Ld°2, Ld (Algae)1, (As+Ag)1. Lower boundary diffuse.
691 - 736	4	Clayey algal gyttja, light greenish-brown. Composition: Ld°2, Ld (Algae)1, (As+Ag)1 Lower boundary sharp.
736 -	5	Silty sand, bluish-grey. Composition, Ag2, (Ga+Gs)2

VI. POLLEN ASSEMBLAGE ZONES

Delimitation of the pollen assemblage zones (p.a.z.'s) has been on the basis of the main Wielkie Gacno profile. All the pollen profiles from Lake Wielkie Gacno have been compared and the same p.a.z.'s are recorded throughout. Since only one lake basin has been investigated these p.a.z.'s are considered to be local.

When the pollen diagrams from Wielkie Gacno are compared with others from the surroundings certain similarities are observed. First of all, the peat bog investigation of Kepczyński (1958) from the Tuchola forest-district is worthy of mention. His pollen curves in the diagram from Siwe Bagno follow, in the main, the same trend as those in the main diagram discussed here. This could perhaps be considered sufficient criteria for calling the local p.a.z.'s in the Wielkie Gacno profile regional ones, and typical, at least, of the Tuchola pine forest-district.

In some diagrams from the Tuchola forests, especially from the northern part, the rational limit of *Alnus* is almost simultaneous with that of *Tilia* (e.g. Borówko-Dużkowska 1962, Kirkor 1970, Prusinkiewicz & Noryskiewicz 1975), appearing several hundred years later than in the other investigated parts of the Tuchola forests. This may have had something to do with the early distribution of *Alnus incana*. *Alnus incana* is a pioneer species with moderate base status requirements. It prefers soils of alluvial origin and grows willingly on the lowest terraces of rivers, on the edges of lakes, around marshes, low peat bogs and in seepage regions (Boratynska & Boratyński 1979). It may be possible that the first maximum of *Alnus* during the Boreal and Early Atlantic chronozones in the Wielkie Gacno diagram is due to the occurrence of *Alnus incana* at the site, because the soils were not yet too acid for this tree. Therefore, that difference may be excluded when determining the regionality of the pollen assemblage zones.

The local pollen assemblage zones are described according to the discussion in chap. IV:6. The radiocarbon dates are given as radiocarbon years before present (Half-life of ^{14}C 5568 years), (Fig. 19).

WG 1 *Pinus-BETULA* local pollen assemblage zone (1310.0 cm - 1302.5 cm).

Description: Very high frequencies of *Pinus* (c. 80 %) which decrease in the later part of the zone. *Betula* shows a simultaneous increase finally reaching about 35 %. NAP has high values (10-15 %) which, however, decrease distinctly towards the end of the zone. In the later part of the zone the first occurrences of *Corylus* and *Ulmus* are recorded, and *Juniperus* has its maximum (4-5 %, the highest values for the whole Holocene).

Boundaries: The lower boundary is drawn where *Juniperus* pollen percentages fall below 5 %.

Age: The lower boundary is not radiocarbon dated but the zone can be correlated with the earlier part of the Pre-boreal chronozone.

Remarks: The lower boundary corresponds to the lithological limit between sand and gyttja in the main profile and, in those profiles where

the Late-Glacial sediments are presented, to the limit between clay gyttja and gyttja.

WG	LOCAL POLLEN ASSEMBLAGE ZONES		14C-DATES BP	CHRONOZONES
	ZONES	SUBZONES		
WG 8	<i>Pinus-BETULA</i>	<i>Pinus</i>	1310.0	SUBBOREAL
WG 7	<i>Pinus-BETULA</i>	<i>Pinus</i>	1302.5	
WG 6	<i>Pinus-BETULA</i>	<i>Pinus</i>	1295.0	
WG 5	<i>Pinus-BETULA</i>	<i>Pinus</i>	1287.5	
WG 4	<i>Pinus-BETULA</i>	<i>Pinus</i>	1280.0	SUBATLANTIC
WG 3	<i>Pinus-BETULA</i>	<i>Pinus</i>	1272.5	
WG 2	<i>Pinus-BETULA-CORYLUS</i>	<i>Pinus</i>	1265.0	
WG 1	<i>Pinus-BETULA</i>	<i>Pinus</i>	1257.5	
WG 0	<i>Pinus-BETULA</i>	<i>Pinus</i>	1250.0	ATLANTIC
WG 9	<i>Pinus-BETULA</i>	<i>Pinus</i>	1242.5	
WG 10	<i>Pinus-BETULA</i>	<i>Pinus</i>	1235.0	
WG 11	<i>Pinus-BETULA</i>	<i>Pinus</i>	1227.5	

Figure 18. Comparison between the pollen assemblage zones of Lake Wielkie Gacno and the chronozones as well as the ^{14}C -dates (only the Holocene).

WG 2 *PINUS-BETULA-CORYLUS* local pollen assemblage zone (1302.5 cm - 1252.5 cm).

Description: *Pinus* dominates over the other trees ranging between 55 and 65 %. In the earlier part of the zone *Pinus* shows a slight increase, but in the middle and later part a slow decrease. *Betula* decreases slightly throughout the zone (from c. 35 % to 20 %). *Corylus* increases rapidly and attains its first maximum in the middle part of the zone. The rational limit of *Alnus* also occurs in the middle of the zone. Among the nemoral broad-leaved trees *Ulmus* is dominant with values of 1-3 %. NAP gradually decreases from 10 % to 5 %.

Boundaries: The lower boundary is placed at the rational limits of *Corylus* and *Ulmus*.

Sub-division: The following sub-

zones can be distinguished.

WG 2:1 ULMUS assemblage sub-zone: The Pinus and Betula curves show a slow decrease, Corylus increases rapidly finally reaching about 15 % in the later part of the sub-zone. Ulmus is the only recognized nemoral broad-leaved tree attaining c. 3 % in the later part of the sub-zone. The lower boundary is that of the local pollen assemblage zone.

WG 2:2 ULMUS-ALNUS assemblage sub-zone: In the earlier part of the sub-zone Pinus shows a further decrease but then increases to the same frequencies as in the preceding sub-zone by the end of the sub-zone. Betula values remain largely unchanged. Corylus reaches its first maximum, Quercus is recorded by some single finds. The lower boundary is drawn at the rational limit of Alnus.

Age: The local pollen assemblage zone is correlated with the upper part of the Pre-boreal chronozone. The lower boundary is about 9 700 B.P. and the boundary between the sub-zones about 9 100 B.P.

WG 3 PINUS-BETULA-CORYLUS-ALNUS local pollen assemblage zone (1252.5 cm - 1140.0 cm).

Description: Pinus predominates through the zone. In the lower part its values range between 45 % and 50 %, while Betula has values of 15-20 %. In the later part Pinus is very unstable having frequencies 35-75 % and Betula simultaneously decrease to less than 10 %. After a rapid increase to over 5 % Alnus pollen values rise slowly to reach c. 10 % by the middle of the zone after which they fall somewhat in the upper part of the zone. The frequency of Corylus remains virtually unchanged (8-12 %). Ulmus and Quercus have equal frequencies, 3-4 %. NAP percentages are the same as in the previous zone.

Boundaries: The lower limit is placed where Alnus is rapidly increasing and Quercus has its rational limit.

Sub-division: The following sub-zones are delimited:

WG 3:1 ULMUS-QUERCUS assemblage sub-zone: Pinus and Betula frequencies remain unchanged, Alnus shows a steady increase reaching about 7 %. Corylus decreases slightly and Fraxinus and Tilia appear as scattered finds. The lower boundary is that of the local pollen assemblage zone.

WG 3:2 QUERCUS-ULMUS assemblage sub-zone: Ulmus and Quercus are equally represented or Quercus becomes dominant over Ulmus. Tilia and Fraxinus begin to appear regularly, although, in very low frequencies. The lower boundary is placed where Alnus values rise above 7 % and Quercus over 3 %.

Age: The lower boundary is about 8 900 B.P., and the boundary bet-

ween the sub-zones is about 8 700 B.P. It can be correlated with the Boreal and the lower and middle parts of the Early Atlantic chrono-zones.

WG 4

PINUS-BETULA-CORYLUS-ALNUS-ULMUS local pollen assemblage zone (1240.0 cm - 995 cm).

Description: In the lower part Pinus decreases to around 35-40 % and in the middle and upper parts it is very irregular (30-65 %). Alnus and Corylus remain unchanged (10-15 %). Ulmus attains its maximum of 5-8 % in the lower part and then decreases slightly. Tilia and Fraxinus range between 1 and 2 %, Acer and Fagus are found sporadically. Picea has an unbroken curve in the middle and upper part of the zone (1-2 %). NAP remain unchanged, Calluna shows a distinct increase attaining about 5 % towards the end of the zone.

Boundaries: The lower limit is placed at the rational limit of Tilia.

Sub-division: The following sub-zones are recorded:

WG 4:1 QUERCUS-TILIA assemblage sub-zone: Pinus decreases suddenly to 35-40 %. Betula increases gradually to 5-10 %. Alnus shows a distinct increase reaching 10-15 %. Ulmus and Quercus continue to increase. The lower boundary is that of the local assemblage zone.

WG 4:2 QUERCUS-TILIA-FRAXINUS assemblage sub-zone: Pinus frequencies are irregular, ranging between 30 and 65 %, Betula fluctuates between 10 and 20 %. Quercus assumes greater dominance among the nemoral broad-leaved trees, while Ulmus decreases slightly. The lower boundary is placed at the rational limit of Fraxinus.

Age: The lower boundary of this zone is about 7 200 B.P. and the boundary between the sub-zone about 6 900 B.P. The zone can be correlated with the middle and earlier part of the Late Atlantic chronozone.

WG 5

PINUS-BETULA-QUERCUS-CORYLUS-ALNUS local pollen assemblage zone (995 cm - 835 cm).

Description: Pinus shows a continuous steady increase. Betula, Alnus and Corylus curves are stable at values between 10 and 15 %, with Alnus increasing slightly. Quercus reaches its maximum (about 15 %) in the upper part of the zone. Ulmus falls below 1 % in the middle part but increases again to attain a value of 2 %. Tilia has a distinct minimum simultaneous with that of Ulmus and thereafter occurs only sporadically. Fraxinus has low but regular values (2-3 %) and decreases slowly in the upper part of the zone.

Boundaries: The lower boundary is placed where Quercus pollen values finally exceed 8 % and where Pinus frequencies fall distinctly.

Sub-division: The following sub-zones are recognized:

WG 5:1 ULMUS-TILIA-FRAXINUS assemblage sub-zone: Pinus increases following its strong decrease, reaching values of 40-45 %. Corylus and Quercus increase to maximum values (12-14 %) in the upper part of the sub-zone. Ulmus declines distinctly in the middle but then increases slightly to attain 3 % in the upper part of the sub-zone, after which values fall again. Tilia shows a further regular decrease. The lower zone boundary is that of the local pollen assemblage zone.

WG 5:2 ULMUS-FRAXINUS assemblage zone: Pinus dominates (40-45 %) and Betula fluctuates between 10 and 20 %. Quercus has a maximum 10-15 % in the lower part of the sub-zone and then slowly decreases. Ulmus pollen values rise above 1 % simultaneous with the Quercus pollen values rise above 1 % simultaneous with the Quercus maximum. Carpinus and Picea have low but increasing pollen frequencies in the upper part of the sub-zone. The lower boundary is placed at the strong decrease in Tilia and where Ulmus values fall below 0.5 %.

Age: This zone corresponds to the later part of the Atlantic and the Early Sub-boreal chronozone. The lower boundary of this zone is about 5 500 B.P. and the boundary between the sub-zones is about 4 300 B.P.

WG 6 PINUS-BETULA-ALNUS-CARPINUS local pollen assemblage zone (835 cm - 690 cm).

Description: Pinus dominates throughout the zone with values of 35-60 %. Alnus has high pollen values (10-15 %) but these decrease slightly in the upper part, Corylus frequencies fall successively to below 5 % in the middle part of the zone. Quercus ranges between 5 and 10 % and decreases to c. 5 % simultaneous with Corylus-decrease. There is a consistent trend throughout the zone of increasing Carpinus percentages from bottom to top. Ulmus, Tilia, Fraxinus disappear almost totally in the middle part of the zone, and occur thereafter only sporadically. Picea has its highest frequencies during the Holocene in the upper part of the zone.

Boundaries: The lower limit is drawn where Carpinus and Picea values exceed 1 % and where Corylus frequencies begin to fall.

Sub-division: The following sub-zones are delimited:

WG 6:1 QUERCUS-ULMUS-PICEA-CORYLUS assemblage sub-zone: Pinus shows a slight increase while the values for Betula are the same as in the preceding zone (WG 5:2), Alnus remains more or less unchanged in the lower and middle part of the sub-zone and then decreases by about 5 %. Corylus decreases

regularly. The frequencies of Ulmus and Tilia fall below 1 %, the curve for Carpinus rises and exceeds 5 %, and Picea percentages are between 1 and 2 %. The lower boundary of the local pollen assemblage zone.

WG 6:2 QUERCUS-PICEA assemblage sub-zone: In the middle part Alnus decrease by 10 %, Corylus and Quercus values are consistently lower than in the preceding sub-zone with frequencies of 3-4 % and 3-6 % respectively. Carpinus increases distinctly, and Picea has a maximum in the middle part of the sub-zone. The lower boundary is placed where the curves of Ulmus and Tilia are obviously fall.

Age: This zone is correlated with the Middle - Late Sub-boreal and the Early Sub-atlantic chronozone. The lower limit is around 3 700 B.P. and the boundary between the sub-zones about 2 700 B.P.

WG 7 PINUS-BETULA-ALNUS-CARPINUS-FAGUS local pollen assemblage zone (690 cm - 552.5 cm).

Description: Pinus pollen values fall to begin with but increase distinctly in the middle and upper part, Betula values are quite high (15-20 %), but falling simultaneous with the Pinus-increase. Alnus, Corylus and Quercus values are stable but decrease slightly in the upper part. Fagus exceeds 2 % in the lower part and then remains unchanged. Picea falls below 1 % in the middle part of the zone. NAP pollen increases slightly to attain 10 % or more in the upper part.

Boundaries: The lower boundary is drawn at the rational limit of Fagus.

Sub-division: The following three assemblage sub-zones are distinguished:

WG 7:1 QUERCUS-PICEA assemblage sub-zone: Pinus decreases slowly and Betula increases. Fagus and Picea have pollen values of 2-3 %, Quercus and Alnus frequencies increase slightly. In the upper part of the sub-zone NAP values rise to nearly 10 %. The lower boundary is that of the local pollen assemblage zone.

WG 7:2 QUERCUS assemblage sub-zone: Pinus increases steadily. In the middle part of the sub-zone Alnus reaches its maximum of c. 15 % and then decreases slightly. Carpinus also has its maximum in the middle part, exceeding c. 10 %. The lower boundary is drawn where the Picea frequencies finally fall.

WG 7:3 PINUS-QUERCUS assemblage sub-zone: Pinus increases by about 20 %, reaching values of 65-70 % in the upper part. All the other trees have falling values. NAP values rise to 12-14 %, among which Rumex and Cerealea increase distinctly. The lower boundary is positioned

where Pinus pollen values exceed 50 %, where Betula frequencies begin to fall and where Rumex and Cerealea curves have a distinct rise.

Age: This zone is correlated with the Middle and Late Subatlantic chronozone. The lower limit of the zone is about 2 000 B.P. and the boundaries between the sub-zones about 1 500 B.P. and 900 B.P.

WG 8 PINUS local pollen assemblage zone (522.5 cm - 507 cm).

Description: The nemoral broad-leaved trees disappear virtually completely. Juniperus increases to c. 3-4 % and NAP reach 15 % or more.

Boundaries: The lower boundary is placed where the Pinus-curve increases dramatically and the values of Carpinus fall below 1 %.

Age: This zone can be correlated with the upper part of the Late Sub-atlantic chronozone, the lower boundary is assumed to be about 100 B.P.

The description of the local Late-Glacial pollen assemblage zones has been made on the basis of the macrofossil-pollen diagram WG A1, which has the thickest sediment layers of Late-Glacial age. In the other macrofossil diagrams (WG A2, WG A3 and WG B1) Late-Glacial sediments are also present, but they are more compact and sometimes the oldest part is missing (WG B1).

WG a PINUS-CYPERACEAE local pollen assemblage zone (372 cm - 375 cm)

Description: Pinus dominates with pollen values of over 70 %, and Betula attains frequencies of about 10 %. Corylus alone occurs as a secondary pollen grain 3 %. Herb pollen values are rather low and dominated by Cyperaceae which increases in the upper part of the zone to reach values of 10 % or more. Gramineae is present at 2 % or more but other herb frequencies are insignificant, Saxifraga, however, is found fairly frequently.

Boundaries: This is the lowest zone recorded in the sediments from Lake Wielkie Gacno.

Age: There are no radiocarbon dates from this zone, but it is assumed to be comparable to the time before the Allerød chronozone.

WG b PINUS-BETULA-GRAMINEAE local pollen assemblage zone (359.5 cm - 372.0 cm).

Description: The curve of Pinus rises markedly in the lower part from values of below 50 % and values exceed 70 % in the upper part of the zone. Betula frequencies decrease falling by about 10 % during the zone. There is a small rise in Juniperus (c. 2-3 %) in the beginning of the zone. NAP values are low, falling from 17-20 % to under 10 %. Gramineae is

the dominant herb pollen type with values of 2-4 %. Artemisia has values of 2 % or more. In the lower part Saxifragaceae and Helianthemum occur.

Boundaries: The lower boundary is drawn where Pinus falls dramatically, where Betula values exceed 30 % and where the curves of Juniperus and Artemisia begin to rise.

Age: The lower boundary is radiocarbon dated to 11 840 ± 110 B.P. so the zone may correspond to the Allerød chronozone.

WG c JUNIPERUS-GRAMINEAE-ARTEMISIA local pollen assemblage zone (326.0 cm - 359.5 cm).

Description: Juniperus dominates throughout the whole zone with values of 25 % or more. Pinus pollen frequencies are between 20 and 40 % and those of Betula between 10 and 20 %. Herb pollen percentages are higher than in the underlying zone, and dominated by Gramineae and Artemisia with values of at least 10 %, and 5 % respectively. In the middle and upper part of the zone the frequencies of Saxifraga, Anemone-type, Chenopodiaceae and Rumex are at least 1 %. Dryas is found throughout the whole zone.

Boundaries: The lower boundary is placed where Juniperus pollen values exceed 10 %, Gramineae and Artemisia 5 % and where Pinus pollen frequencies fall below 70 %. The upper boundary is drawn where Juniperus frequencies fall below 10 % and where Pinus pollen values exceed 40 %.

Sub-division: The following sub-zones are recognized:

WG d:1 JUNIPERUS assemblage sub-zone: Juniperus increases suddenly to 30 % and then rises steadily to 50 % or more but in the upper part of the sub-zone its frequencies decrease. Pinus decreases by 15 % and Betula simultaneously increases reaching 15-20 %. In the middle and upper part of the sub-zone there is a marked rise of Anemone-type. Helianthemum and Saxifraga have their maxima at the same time. Gramineae and Cyperaceae increase slowly. The lower boundary is the lower boundary of the local pollen assemblage zone.

WG d:2 PINUS-BETULA assemblage sub-zone. AP pollen values are higher than those of Juniperus throughout the sub-zone. Pinus and Betula have steady values of 30-35 % and 15-20 % respectively. Juniperus decreases slightly having values between 20 and 25 %. Gramineae, Cyperaceae and Artemisia as well as all the steppe elements decrease in the upper part of the zone. The lower boundary is positioned where Juniperus pollen values fall below 30 % and where Pinus

and Betula frequencies begin to rise.

Age: The lower boundary is radiocarbon dated to $11\,380 \pm 100$ B.P. but that age is thought to be somewhat too old. The assemblage zone may correspond to the Younger Dryas chronozone.

VII. 14C CHRONOLOGY AND CHRONOZONES

Radio-carbon dates were obtained from the Holocene material in order to obtain an absolute chronology for the pollen assemblage zone-boundaries and to determine the rate of sediment accumulation. By means of these values a pollen influx diagram has also been constructed. Samples were taken at about 50 cm intervals. For the Late-Glacial material the important pollenzone boundaries and pollen floristic levels were dated.

The datings are listed in Tab. 4.

Table 4. Radio-carbon dates.

Sample	Depth below water surface, cm	B.P.	Age $T_{1/2}$: 5568 A.D./B.C.
<u>Main profile:</u>	(water depth 505.0 cm)		
Lu-1541. Detritus gyttja, brown. Just below the boundary WG 8/WG 7. At the distinct increase in <u>Pinus</u> and decrease in <u>Carpinus</u> .	530.0 - 535.0 530.0 - 535.0	780+50 780+50	1170 A.D. 1170 A. D.
Lu-1540. Detritus gyttja, brown. Above the boundary WG 7:3/WG 7:2. At the increase of <u>Pinus</u> .	580.0 - 585.0	1220+50	730 A.D.
Lu-1613. Detritus gyttja, brown. Above the boundary WG 7:2/WG 7:1. At the distinct decrease in <u>Picea</u> . Somewhat below the last maximum of <u>Carpinus</u> .	630.0 - 635.0	1790+50	160 A.D.
Lu-1612. Detritus gyttja, brown. Somewhat above the boundary limit of <u>Fagus</u> .	680.0 - 685.0	2250+50	300 B.C.
Lu-1611. Detritus gyttja, brown. Middle part of WG 6:2. At the <u>Picea</u> -maximum and the further decrease in <u>Corylus</u> and <u>Quercus</u> . Just above the final decrease in <u>Ulmus</u> .	730.0 - 735.0	2650+55	700 B.C.
Lu-1610. Detritus gyttja, dark brown. Middle part of WG 6:1. Somewhat below the final decrease in <u>Tilia</u> .	780.0 - 785.0	3320+55	1370 B.C.
Lu-1609. Detritus gyttja, dark brown. At the boundary WG 6/Wg 5. Somewhat above the rational limit of <u>Carpinus</u> and somewhat below the final decrease in <u>Fraxinus</u> .	830.0 - 835.0	3740+55	1790 B.C.
Lu-1608. Detritus gyttja, dark brown. The earlier part of WG 5:2. Further decrease in <u>Ulmus</u> and <u>Tilia</u> .	880.0 - 885.0	4230+60	2280 B.C.
Lu-1470. Algal gyttja, dark brown. The upper			

part of WG 5:1. The increase in <u>Quercus</u> and <u>Corylus</u> .	930.0 - 935.0	4810 _± 60	2860 B.C.
Lu-1539. Algal gyttja, dark brown. Middle part of WG 5:1. At the <u>Ulmus</u> decline.	950.0 - 955.0	5130 _± 60	3180 B.C.
Lu-1538. Algal gyttja, dark brown. Somewhat above the boundary WG 5/WG 4. Further increase in <u>Quercus</u> .	980.0 - 985.0	5430 _± 65	3480 B.C.
Lu-1537. Algal gyttja, dark brown. Upper part of WG 4:2.	1030.0 - 1035.0	5950 _± 65	4000 B.C.
Lu-1469. Algal gyttja, dark greenish-brown. Middle part of WG 4:2.	1080.0 - 1085.0	6590 _± 70	4640 B.C.
Lu-1536. Algal gyttja, dark greenish-brown. Middle part of WG 4:1. Somewhat above the rational limit of <u>Tilia</u> and just below that of <u>Fraxinus</u> .	1130.0 - 1135.0	7160 _± 75	5210 B.C.
Lu-1535. Algal gyttja, dark greenish-brown. The upper part of WG 3:2.	1180.0 - 1185.0	8120 _± 80	6170 B.C.
Lu-1534. Algal gyttja, dark greenish-brown. At the boundary between WG 3:2/WG 3:1. The further increase in <u>Quercus</u> and <u>Alnus</u> .	1230.0 - 1235.0	8350 _± 80	6400 B.C.
Lu-1533. Algal gyttja, dark greenish-brown. At the boundary WG 3/WG 2. Somewhat below the rational limit of <u>Quercus</u> and the distinct increase in <u>Alnus</u> .	1255.0 - 1260.0	8830 _± 85	6880 B.C.
Lu-1532. Algal gyttja, dark greenish-brown. Middle part of WG 2:1. Further increase in <u>Corylus</u> , somewhat above the rational limit of <u>Ulmus</u> .	1280.0 - 1285.0	9280 _± 90	7330 B.C.
Lu-1531. Algal gyttja, dark greenish-brown. At the boundary WG 2/WG 1. Just below the rational limit of <u>Ulmus</u> , at the decrease in <u>Pinus</u> and <u>Betula</u> .	1304.0 - 1308.0	9870 _± 90	7920 B.C.

Wielkie Gacno A1 - profile:

Lu-1481. Clay gyttja, dark greenish-grey. At the boundary WG c:2/WG c:1. The increase in <u>Pinus</u> and <u>Betula</u> , further decrease in <u>Juniperus</u> and steppe elements.	335.0 - 340.0	11,000 _± 100	9050 B.C.
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Lu-1680. Sandy clay gyttja, light greenish-grey. Middle part of WG c:1. Somewhat below the Juniperus maximum. Further increase in Gramineae, Artemisia and Helianthemum. 348.0 - 352.0 11,100±105 9150 B.C.

Lu-1679. Clayey algal gyttja, dark greenish-brown. At the boundary WG c/WG b. At the distinct increase in Juniperus and decrease in Pinus. 356.0 - 360.0 11,380±100 9430 B.C.

Lu-1678. Algal gyttja, dark brown. At the boundary WG c/WG b. At the distinct increase in Pinus and the decrease in Cyperaceae. 367.0 - 371.0 11,840±110 9890 B.C.

Archaeological samples:

Age T1/2: 5568

Sample	B.P.	A.D./B.C.
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Lu-1637. Wood from a dugout canoe (Pinus sp.) recovered from the bottom mud c. 12 cm from the south-eastern shore of Lake Wielkie Gacno. (The canoe belongs to the collection of the Museum of Ethnography in Torun/catal. no. MET/KW/16318/). 810±50 1140 A.D.

Although the water of Lake Wielkie Gacno seems to have a very high content of calcium there is any traces of a hard-water effect (see e.g. Donner et al. 1971).

By plotting the radio-carbon dates against time and depth (Fig. 19) it seems apparent that the age of the upper samples (Lu-1541, Lu-1540, Lu-1613, Lu-1612) may deviate from the true age. The error increase towards the top. The uppermost dating (Lu-1541) seems to show an age which is c. 500 years too high (Table 5). This may have been caused by prehistoric and historic agricultural activity in the surrounding area. Due to the relatively slight human impact in the immediate neighbourhood of Lake Wielkie Gacno the differences between the radio-carbon dates and assumed true ages are quite small and increase regularly towards the sediment surface. Evidence of a similar error caused by the erosion of older organic material into the lake basin has been found in Scandinavia (e.g. M. Tolonen 1978, Huttunen & Tolonen 1977, Batterbee et al. 1976, Jóhansen 1975).

The correction needed due to the field erosion mentioned above is based on the assumption that the accumulation rate has remained constant during the late Holocene.

Lu-1681 and Lu-1680 show almost the same age. The material in question is of Late-Glacial age. On the basis of the pollen evidence and lithological data the sediment could be correlated with the Younger Dryas chronozone. Lu-1681 is thought to be too old as a result of assumed palaeolimnological changes in the lake leading to a mixture of older material or dissolved products from older deposits. Such an inaccurate radio-carbon date may also be caused

by a methodological or statistical error.

The immigration of the different trees during the Holocene in relation to the absolute chronology will be discussed later in Chapt. IX as part of the description of the regional vegetation history.

In Fig. 19 the radio-carbon dates are plotted against depth below sediment surface

Table 5. Corrections applied to the Holocene radio-carbon dates

Laboratory No.	Uncorrected radio-carbon age (B.P.)	Corrected age (B.P.)	Correction (approximatively)
Lu-1541	780 - 50	275	- 500
Lu-1540	1220 - 50	875	- 350
Lu-1613	1790 - 50	1450	- 350
Lu-1612	2250 - 50	2075	- 175
Lu-1611	2650 - 55	2600	- 50
Lu-1610	3320 - 55	3150	- 150
Lu-1609	3740 - 55	3750	-
Lu-1608	4230 - 60	4300	+ 50
Lu-1470	4810 - 60	4900	+ 100
Lu-1539	5130 - 60	5130	-
Lu-1538	5430 - 65	5430	-
Lu-1537	5950 - 65	5950	-
Lu-1469	6590 - 70	6590	-
Lu-1536	7160 - 75	7160	-
Lu-1535	8120 - 80	7800	- 300
Lu-1534	8350 - 80	8550	+ 200
Lu-1533	8830 - 85	8975	+ 150
Lu-1532	9280 - 90	9350	+ 50
Lu-1531	9870 - 90	9775	- 100



Figure 19. ^{14}C -dates plotted against depth and the graphically fitted time-depth curve.

to produce a curve indicating the rate of sediment accumulation. Dates for the boundaries between the pollen assemblage zones and assemblage sub-zones have been arrived at by interpolation based on the graphically fitted time-depth curve. The chronozone and sub-chronozone boundaries in the pollen diagram have been fixed by means of the same curve.

Calculated from the time-depth curve the rate of sediment accumulation is thought to have been below c. 1 200 cm 0.63 mm/year and above c. 1 130 cm the line gives a mean accumulation rate of 0.85 mm/year. This line is straight and thus gives a correct age for the surface sediment. Between 1 130 cm and 1 200 cm the rate shows an increase from 0.63 to 0.85 mm/year.

Chronozones

Pollen diagrams produced in connection with previous pollen-analytical investigations in Poland have been zoned according to the zonation system originally used for describing climatic change by Blytt (1875) and Sernander (e.g. 1908). This classification was soon taken over as a method for interpreting and correlating vegetational changes in Quaternary Geology. Later on geologists and botanists modified the system into a biostratigraphical instrument in which the zones were marked by numbers or letters. Knud Jessen (1935, 1938) developed the pollen-zone systems for the Late-Glacial and Holocene which are widely used in Norden, and which were later modified for application to central Europe by Firbas (1949, 1952). In the central and north Polish palynological investigations Jessen's and Firbas' and sometimes also Nilsson's (1935) zone system have provided the basis for the biostratigraphical pollen zone system and due to the lack of radio-carbon dates the present-day chronostratigraphical terms Pre-boreal, Boreal, Atlantic, Sub-boreal, Sub-atlantic have been used as biostratigraphical units. The same concerns the zoning of pollen diagrams of Late-Glacial age.

Since the vegetational changes were not synchronous in Norden and Central

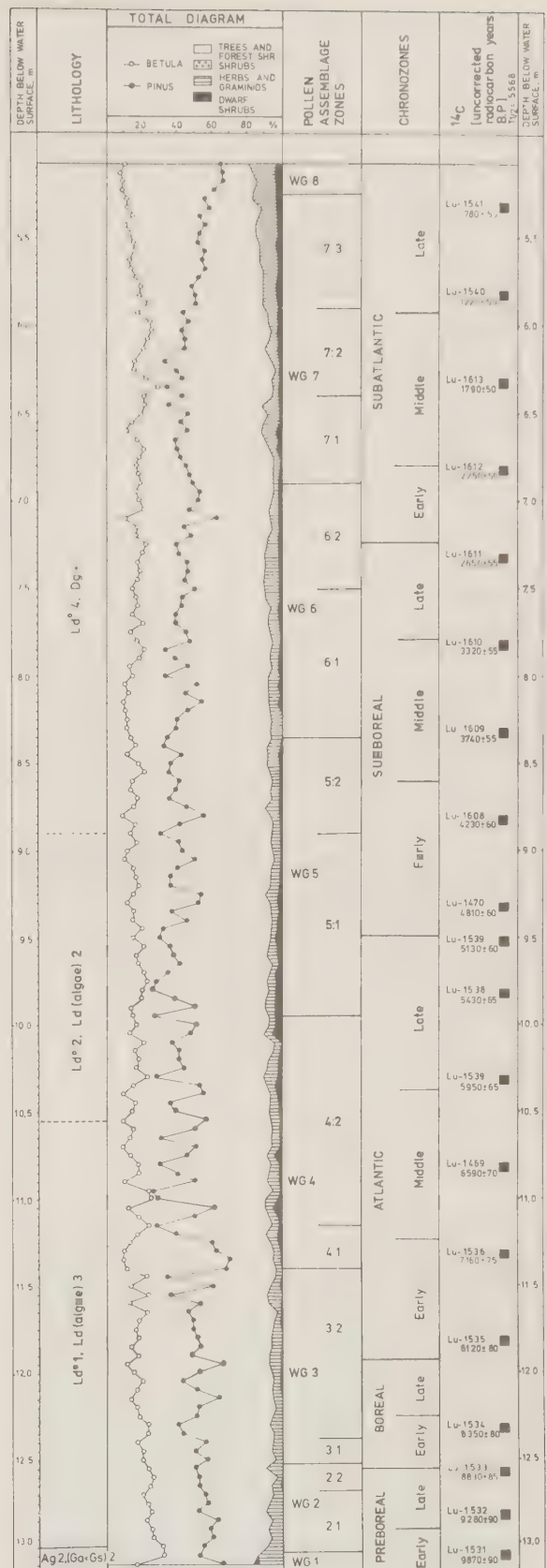


Figure 20. Comparison between the Holocene PAZ's of Lake Wielkie Gacno (marked by letters and numbers) and the chronozones and their relation to the main vegetational features in the area.

POLLEN ASSEMBLAGE ZONES		CHRONOZONES	
WIELKIE GACNO HJELMROOS	WITÓW WASYLIKOWA, 1964	MANGERUD ET AL. 1974	
PINUS- BETULA	PINUS- BETULA	PREBOREAL	
JUNIPERUS- GRAMINEAE- ARTEMISIA	JUNIPERUS- ARTEMISIA- GRAMINEAE	YOUNGER DRYAS	
PINUS- BETULA	PINUS- BETULA	ALLERØD	
PINUS- CYPERACEAE	PINUS- HIPPOPHAE- CYPERACEAE	OLDER DRYAS	

Figure 21. Comparison between the Late-Glacial PAZ's in Lake Wielkie Gacno and those of Wasylikowa (1964) from Witow, (proposed by present author), as well as their relation to the chronozones.

Europe during the Late-Glacial and Holocene pollen zonations gave a false picture of the development. Mangerud et al. (1974) proposed a definition of chronozones with closely defined boundaries established by means of radio-carbon dating. On the other hand pollen assemblage zones have been used as biostratigraphical units (see the discussion in Chapt. IV:6). A comparison between the pollen assemblage zones and the chronozones is illustrated in Fig. 20 for the Holocene. In Fig. 21 a comparison is made between the Late-Glacial pollen assemblage zones in Lake Wielkie Gacno and those of Wasylikowa (1964) from Witow (proposed by present author) and both are then related to the chronozones.

In Fig. 22 the Wielkie Gacno pollen assemblage zones and chronozones are related to the other zone systems used in Poland. These systems of Jessen, Firbas and Nilsson are used as biostratigraphical units and the zone boundaries are defined on the basis of the pollen analytical evidences.

14 C	CLIMATIC ZONES	POLLEN ZONES				CHRONOZ	
B.P.	BYTT 1875 SERANDER 1900	FIRBAS 1949	JESSEN 1935, 1938	NILSSON 1935	NILSSON 1961, 1964	HJELMROOS WIELKE GACNO 1974	
5500		X	IX	I	SA2	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - PR	Subatlantic Late
1000	SUBATLANTIC PERIOD (climate humid of the beginning cold)	IX		II	SA1	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - PR	Subatlantic Middle
2000							
3000	SUBBOREAL PERIOD (climate dry and warm)	VIII	VIII	III	SB2	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - UI - Pc - Co	Subboreal Late
4000							
4000				IV	SB1	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - UI - Pc - Co	Subboreal Middle
5000		VII					
6000	ATLANTIC PERIOD (climate mild and maritime)	VI	VII	V	AT2	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - UI - Pc - Co	Atlantic Late
7000							
8000		V	VI	VI	AT1	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - UI - Pc - Co	Atlantic Middle
8000	BOREAL PERIOD (climate dry and warm)		V	VII	BO2	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - UI - Pc - Co	Boreal Late
9000			IV	VIII	BO1	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - UI - Pc - Co	Boreal Middle
9000	SUBARCTIC PERIOD (climate cool, more or less undetermined)	IV	III	IX	PBO	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - UI - Pc - Co	Subarctic Late
10000							
10000	ARCTIC PERIOD (climate as in Greenland)	III	II		DR3	PINUS - BETULA - ALNUS - CORYLUS - FAGUS - QU - UI - Pc - Co	Arctic Early
11000							

Figure 22. Holocene pollen assemblage zones from Lake Wielkie Gacno and the chronozones related to the other, in Poland, biostratigraphically used zone systems of Jessen, Firbas and Nilsson.

VIII. RECENT POLLEN SEDIMENTATION

An attempt to demonstrate the regional representativity of Lake Wielkie Gacno has been made on the evidence of recent pollen sedimentation in 7 different lakes situated in the same vegetational region, the Tuchola pine woods (Fig. 13).

1. Description of localities and surface pollen spectra

In choosing the localities for the study of recent pollen sedimentation attention has been paid to the situation (that it is in the same district as Lake Wielkie Gacno), and ecology of the lake. Many of the lakes chosen are also being investigated by limnologists from Toruń.

a. Wegner

Lake Wegner is situated about 2 km east of Charzykowy and 1 km north-west of Chojniczki. The greatest length and breadth of the lake are c. 6 000 m and 300 m respectively, and it is oval in shape in NE-SW direction.

Wegner is surrounded by fields and meadows. On the eastern and south-eastern shores there is *Quercetum mixtum* forest with *Alnus* and *Betula*. On the northern shore there are some *Juniperus*-shrubs and young *Pinus silvestris* saplings. Behind the fields the planted *Pinus silvestris* forest is expanding (Photo 3: a,b,c).

No limnological investigations have been made on this lake.

The surface spectra compare 14 samples taken at every 2.5 cm (0-35 cm). About 1 500 AP pollen grains were counted at each level.

The whole profile is dominated by *Pinus* pollen (40-50 %), the frequencies of *Alnus* and *Betula* are for the whole period, 5-10 % and 10-20 % respectively, and the curve of the *Quercetum mixtum* forest species (mainly *Quercus*) is steady at 5 %. NAP frequencies are quite high, about 30 % in the beginning of the profile decreasing to 25 % in the uppermost samples. The indicators of human activity are well represented, *Cerealea* sometimes attaining values of 10 %.

The absolute pollen concentration values decrease significantly at the 10-12.5 cm level.

b. Głowska

Lake Głowska is situated 1 500 m north-north-east of Lake Wielkie Gacno between lakes Plesno and Bełczak. In size, the lake is 1.8 ha, with maximal length and breadth 315 m 235 m respectively and the maximal water depth 11m. About 1 ha of the area of lake is covered by aquatic vegetation. *Phragmites communis* and *Equisetum* grow along the shores, being especially frequent on the western shore. The western part of the lake is covered by floating-leaved plants mainly *Nymphaea*, *Nuphar* and *Potamogeton* (Photo 4:a,b,c).

Along the shore there is a 40-50 m broad zone of *Betula*, *Quercus*, *Fagus* and

Alnus surrounded by planted *Pinus*-forest with *Vaccinium myrtillus*.

The surface spectra compare only 3 samples (0-7.5 cm) taken at every 2.5 cm. About 1 000 AP pollen grains were counted on each level. *Pinus* pollen dominates of about 55 % in every sample. The frequencies of *Alnus* are slightly higher than these of *Betula* (both about 10 %), and *Quercus* is the only species of the mixed *Quercus* forest to be recorded in the pollen samples. *Quercus* pollen is present at 2 %. Due to the fairly high percentages of *Cerealea* and *Rumex* (5 % and 3-5 % respectively) three frequencies of the human indicators as a whole are relative high.

The absolute pollen values give the same picture.

c. Nierybno

Only about 900 m N-NW of Lake Głowska is lake Nierybno, which is itself about 2 400 m north of Lake Wielkie Gacno. Nierybno is a longish lake oriented in north - south direction with a length of 840 m and breadth of 160 m. The lake area is about 9.0 ha and the greatest water depth 7.5 m. About 0.1 ha of the lake area is covered by macrophytic vegetation, mainly *Phragmites communis* and *Equisetum* which form a small belt along the shore.

Immediately on the shore are some *Betula*, *Alnus* and *Quercus* trees, while planted *Pinus*-forest is expanding about 20 m from the shore. The lake is surrounded by dunes and the soils are very poor and dry. In the narrow zone between the shore vegetation with broadleaved trees and herbs (mostly Gramineae and *Carex*) and the *Pinus*-forest with *Vaccinium vitis-idea*, *Vaccinium oxycoccos*, *Vaccinium myrtillus* and *Pteridium aquilinum* are some *Picea* trees. These occur on the moister soils which are also richer in nutrients and humus (Photo 5:a,b).

Four samples taken at every 2.5 cm constitute the surface profile (0-10 cm). About 1 500 AP pollen grains were counted at each level. *Pinus* pollen dominates at 45-50 % throughout, the *Betula* and *Alnus* curves are both unfluctuating (15 % and 7 % respectively), and *Quercus* ranges between 3 % and 5 %. *Carpinus* pollen occurs in quite high values (1 %) at the beginning, decreasing in the surface sample to less than 0.5 %. Ericaceae frequencies increase to 4 %, and the values of *Juniperus* as of those species indicative of human activity are quite high at the beginning but decrease upwards.

Absolute pollen concentration is high, *Pinus* reaches a value of about 71 000 pollen grains in the first sample. The concentration of several species, however, decreases upwards.

d. Czarne

Lake Czarne is situated about 10 km north of Lake Wielkie Gacno. It is oval in NE-SW direction, 740 m long and with a maximal breadth of 145 m. The lake area is about 8.7 ha and the maximal water depth is 7.8 m. *Lysimachia thyrsiflora*, *Carex rostrata*, *Typha latifolia* and *Clyceria fluitans* are found in the littoral zone and surrounding the lake there is a belt of *Phragmites communis*, *Equisetum* and *Carex*. Young

Alnus, Betula and Fagus saplings occur on the shore and somewhat closer to the planted Pinus-forest these broad-leaved trees occur fully grown. On the southern shore the Pinus-forest is partly mixed with Betula (Photo 6:a,b). The western and SW part of the lake shore has been recently cleared and is now overgrown with grass (Molinia, Galamagrostis etc.), Pteridium aquilinum and Vaccinium myrtillus.

The surface spectra compare 4 samples taken at every 2.5 cm (0-10 cm). About 1 000 AP pollen grains were counted at each level. Pinus pollen dominates throughout. The values for pine decrease in the second sample (5-7.5 cm) by 10 % to 50 % and then increase to reach 60 % in the surface sample. The curves of Betula and Alnus decrease slightly, as do those of the other broad-leaved tree pollen types. Eri-caceae ranges from 2 % to 5 % having its lowest value in the uppermost sample. NAP frequencies are constant at around 15 %, with Gramineae, Rumex and Cerealea clearly dominant.

Absolute pollen concentration is high throughout and increases upwards. Pinus reaches values of 152 000 grains/cm³ in the third sample, at which level all the other species also reach their highest values. In the uppermost sample Betula decreases dramatically (from 38 100 to 800 grains/cm³). Other species decrease, too, but not so strongly. Pinus predominates with 110 000 grains/cm³.

e. Nawionek

About 750 m eastwards of lake Czarne lies Nawionek, which is located between lakes Smarli and Gardliczno and with them forms a lake system oriented in N-S direction. The maximal length and breadth of the lake are 540 m and 315 m respectively. The lake area is 10.5 ha and the greatest water depth 9.8 m.

Along the shore there is a narrow belt of reeds, mainly Phragmites communis and Cladium mariscus, with trees of Betula and less frequently Alnus. Otherwise the whole lake is surrounded by planted Pinus-forest with Calluna and Vaccinium vitis-idea (Photo 7:a,b).

The surface profile compares 4 samples taken at every 2.5 cm (0-10 cm). About 1 000 AP pollen grains were counted at each level. Pinus dominates throughout as is usually the case in these surface profiles. The curve for pine is consistent with values around 55 %. Betula and Quercus frequencies are also constant at 11 % and 4 % respectively. The values for Alnus decrease by 4 % in the third sample to 4 % in the fourth sample. NAP values range from 15 % to 19 %. The human indicatorspecies are represented mainly by Rumex, Cerealea, and Artemisia and, with the exception of Rumex, they decrease upwards.

The absolute pollen concentration values attain their maxima in the second sample and then decrease fairly strongly.

f. Piecki

Piecki is situated on the same line as lakes Czarne and Nawionek and about 1 200 m eastwards from the latter. The lake is triangular in shape about 450 m long and 200 m broad, with an area somewhat smaller than that of Nawionek. On the eastern shore are some houses. The shores of Piecki are covered with macrophytic vegetation forming a belt which sometimes exceeds 20 m in width.

Immediately in the shore-zone grow Betula, Alnus and Fagus with some young Picea-trees, Juniperus and Vaccinium myrtillus. The shore vegetation, however, soon changes to planted Pinus-forest containing Betula (Photo 8:a,b).

The surface profile contains 4 samples taken at every 2.5 cm (0-10 cm). About 1 000 AP pollen grains were counted at each level.

Pinus dominates but decreases by about 15 % over the 4 samples reaching 38 % in the surface sample. Betula increases gradually to 15 %. Alnus and Quercus decrease after quite high values in the second sample. NAP frequencies rise from 25 % to over 30 % and pollen values of the human indicatorspecies increase in the uppermost sample.

All pollen concentration values decrease from their maximum in the second sample.

g. Warszyn

The oval lake, Warszyn, is situated about 4,000 m NE of lake Pietzky and about 16 km N-NE of Lake Wielkie Gacno. It is 835 m long and 510 m broad. The lake area is 35.2 ha and the maximal depth 4.5 m. About 1.1 ha of the lake area is covered by aquatic vegetation, with a Phragmites - Equisetum - Carex - belt along the NW shore. The western and southern parts of the lake are quite shallow with a sandy bottom. Betula, some Alnus, Fagus and Sorbus intermingled with grasses and Juniperus grow along the shore. To the west of the lake are some houses surrounded by fields and meadows. The lake is directly bounded to the east by planted Pinus-forest (Photo 9:a,b).

The surface profile compares 4 samples taken at every 2.5 cm (0-10 cm). About 1,000 AP pollen grains were counted on each level. The Pinus curve increases from 38 % to 60 % attaining its highest values in the third sample, while in the uppermost sample pine decreases by 15 %. The curves of Betula, Alnus and Quercus developed in the opposite manner. In the fourth sample Carpinus attains frequencies of 2 %. NAP values decrease gradually from over 30 % to around 20 %. The representation of the human indicatorspecies is quite high at the beginning of the series but then decreases slightly.

The absolute pollen concentration values decrease slightly upwards. Pinus reaches its highest values in the third sample (21,000 pollen grains/cm³), and decreases in the surface sample to 6,000 grains/cm³.

h. Wierzchlas

Lake Wierzchlas is situated south of Bory Tucholskie district in a area characterized by intensive agriculture. A deciduous wood with some Taxus is placed adjacent to the lake.

i. Wielkie Gacno

Lake Wielkie Gacno is described in the Chapt. III.

The surface series presented corresponds to the three uppermost samples in the main profile taken with a Digerfeldt-Letteval sampler. The sampling interval is 5 cm and about 3,000 AP pollen grains were counted at each level.



Photo 3.a. The northern shore of Lake Wegner with young Pinus silvestris plants and Betula trees, behind this zone are situating meadows.



Photo 4.a. The western part of Lake Głowka is covered by float-leaved plants. Behind the zone of the broad-leaved trees is growing the planted pine-forest.



Photo 3.b. The greatest part of the lake is surrounded by fields. On the back-ground is the planted Pinus-forest.



Photo 4.b. The shores are occupied by Phragmites communis. On the shore are Betula, Alnus, Fagus and Quercus building a 40 - 50 m broad belt.



Photo 3.c. Along the eastern shore there is growing Quercetum mixtum-forest.



Photo 5.a. Phragmites communis and Carex are building a small belt on the shores of Lake Nierbno. Immediately on the shore there are some broad-leaved trees.

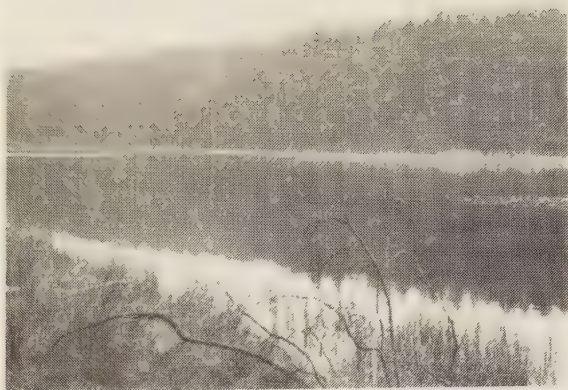


Photo 5.b. Planted pine-forest is spreading out somewhat higher on the shore terrace.



Photo 7.a. On the shore of Lake Nawionek there are found e.g. Phragmites communis, Cladium mariscus and somewhat higher Betula and Alnus.



Photo 6.a. The macrophytic vegetation on the shore of Lake Czarne.



Photo 7.b. The planted Pinus-forest is surrounding the lake.



Photo 6.b. The southern shore is surrounded by pine forest mixed by Betula.



Photo 8.a. Lake Pietcki is surrounded by a Phragmites communis and Carex belt.



Photo 8.b. On the shore of Lake Pietcki Betula and Alnus and Fagus with Picea and Juniperus are found.

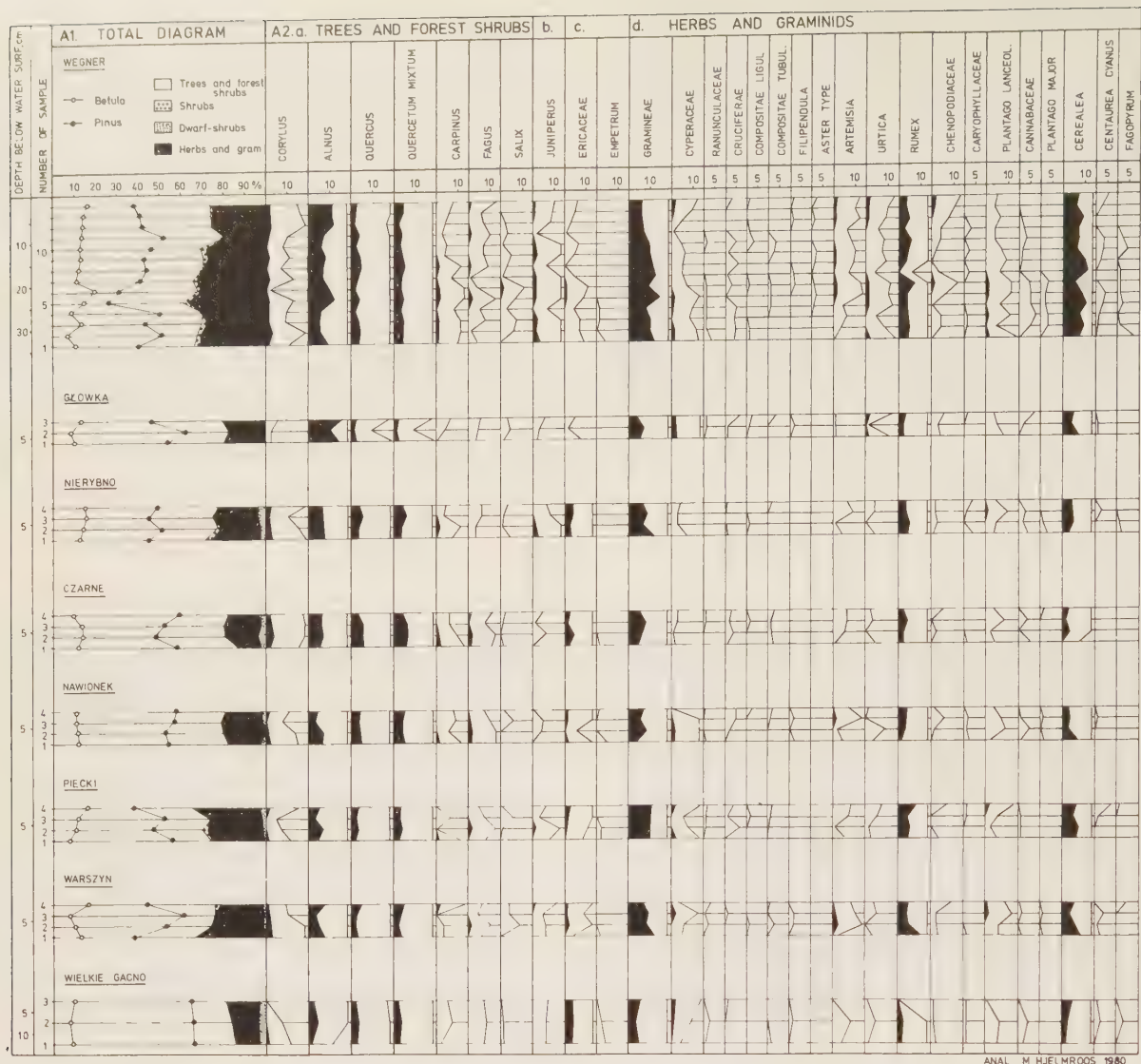


Photo 9.a. The western part of Lake Warszyn is shallow and surrounded by meadows. Along the NW-shore Phragmites communis-Carex belt.



Photo 9.b. Betula, Alnus, Fagus are mixed by Juniperus and Vaccinium on the shore.

(Photo: M.Hjelmroos-Ericsson, 07-1979)



ANAL. M. HJELMROOS 1980

Figure 23. Surface spectra from 8 different lakes in the same vegetational area as Lake Wielkie Gacno,

All pollen curves are quite stable and no great differences are observed between the samples. *Pinus* dominates at 65 % and, therefore, it is quite difficult to follow the development of the other species. However, *Cerealea* increases in the uppermost sample both in relative and absolute values.

2. Comparison of the results with the vegetation cover of today

All the lake basins are small and most of them are surrounded by dense forests. According to Tauber (1977), in such cases, most of deposited pollen grains originate from a relatively small area corresponding to the vegetation surrounding the basin.

Some general remarks can be made when comparing the recent pollen spectra with the modern vegetation. All diagrams

(Fig. 23) are strongly dominated by AP pollen within which *Pinus* is predominant. The *Alnus* frequencies show some over-representation as do those of *Quercus*. In the Wegner-profile, where cultivated land is in the immediate vicinity of the lake basin NAP frequencies are c. 25 % (indicators of human activity about 15 %). In the area between lakes Warszyn and Piecki there are meadows and a young forest which explains why the NAP pollen are found at such high frequencies in the surface spectra. Pollen grains of cereals are found in all samples including those from lakes within the forested region. Cereal percentages were 2.5 - 7.5 % of the total pollen sum. On the shores of Warszyn, Piecki and Głowska there are some houses with meadows and fields which were cultivated in the beginning of 20th century at least. Those around Warszyn are still cultivated today (cf. maps from 1874, 1875 and modern ones). In those diagrams the *cerealea* values are about 2 - 2.5 % higher than in the others. *Rumex* pollen values are high (2 - 6 %) in all

spectra, perhaps due to the roadside vegetation. Although the lake shores are uninhabited a road winds to each lake and the vegetation is influenced by man.

The vegetation around the lakes has not been mapped in detail, nor are there any aerial photographs available. For that reason it is not possible to calculate any correction factors for the modern pollen rain and the recent vegetation and more precise conclusions are impossible.

3. Recent pollen spectra in the investigated lake sediments by means of numerical methods

Numerical methods using principal component analysis (PCA) is common in palynological investigations as a method of summarizing a large number of correlated variables in pollen composition within several different sediment profiles. The technique is widely applied when zoning and comparing two or more profiles in search for an objective zonation of the pollen flora of these profiles. A full discussion of the use of numerical methods in the zonation of pollen diagrams is included in Birks (1979) and Birks & Berglund (1979). The mathematics of the PCA are described by, e.g., Davis (1973), Jöreskog et al. (1976).

In connection with the summarizing of the results for the recent pollen sedimentation in the investigated lakes PCA is used as a test to get a more objective picture of the representativity of Lake Wielkie Gacno in Bory Tucholskie district. Numerical methods to determine the relationship between pollen composition of lake sediments and vegetation have been applied by, e.g. Webb (1974), Davis & Webb (1975) and A. Davis (1980).

In order to observe the differences and similarities between the investigated lakes these have been compared with Lake Wierzchlas from another vegetational area (see above).

The data given to the computer are the mean %-values of the three uppermost samples for the 26 most significant pollen types from each lake.

It can be seen in figs. 24 and 25 that the recent pollen spectra in eight of the investigated lakes are numerically rather similar, while the recent sediments in Lake Wierzchlas have quite another pollen composition. The difference between these districts and lakes would probably have been more evident if a greater number of lakes had been compared with each other.

Apart from the fact that the recent sediments in Lake Wielkie Gacno are more dominated by *Pinus* pollen than the remaining seven lakes in the Bory Tucholskie district, which is in accordance with the extremely poor *Pinus*-dominated vegetation, Lake Wielkie Gacno is a good representative for this district.

Table 6. The mean pollen number and percentage values of the three uppermost samples in the surface spectra from 9 different lakes in the Tuchola pine forest-region. As a comparison the corresponding values for Lake Wierzchlas are included. (Only the most important species are given.)

Species	Wlk. Gacno		Wegner		Główka		Nierybno		Czarne		Nawionek		Pietchki		Warszyn		Wierzchlas	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Pinus</i>	2222	65.0	712	44.6	804	53.9	1065	48.9	747	55.6	768	55.3	746	46.4	630	52.7	1028	47.4
<i>Betula</i>	302	9.0	261	14.7	154	11.0	326	15.0	164	14.9	155	11.3	211	13.3	172	11.6	232	10.1
<i>Corylus</i>	22	0.6	33	1.6	5	0.3	34	1.6	31	2.2	15	1.1	14	0.9	20	1.3	56	2.6
<i>Alnus</i>	126	2.2	195	9.7	180	12.5	139	6.3	82	6.2	68	4.9	79	4.8	73	4.9	164	7.6
<i>Quercus</i>	85	2.3	34	2.6	22	1.5	79	3.7	63	4.7	56	4.1	51	3.1	46	3.1	64	3.0
<i>Carpinus</i>	16	0.5	9	0.5	5	0.3	13	0.9	10	1.2	10	0.8	6	0.2	8	0.6	44	2.3
<i>Fagus</i>	26	0.7	16	0.9	4	0.4	10	0.5	15	1.4	13	1.1	11	0.9	10	0.7	4	0.2
<i>Taxus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	1.3
<i>Juniperus</i>	21	0.6	16	0.7	5	0.4	21	1.1	6	0.4	5	0.3	14	0.8	11	0.7	-	-
<i>Ericaceae</i>	120	3.5	10	0.7	8	0.5	75	3.4	45	3.1	19	1.4	31	2.0	19	3.3	5	0.2
<i>Empetrum</i>	6	0.2	-	-	-	-	-	-	-	-	1	0.1	1	0.1	-	-	-	-
<i>Gramineae</i>	142	4.0	156	6.2	85	5.6	159	7.3	92	5.7	99	7.2	163	10.1	120	7.9	164	7.6
<i>Cyperaceae</i>	29	1.0	14	0.5	29	2.0	7	0.3	3	0.2	17	1.2	15	0.9	14	0.9	52	2.5
<i>Cruciferae</i>	1	0.1	2	0.3	3	0.3	1	0.1	4	0.2	5	0.4	7	0.4	1	0.1	3	0.2
<i>Compositae</i>	1	0.1	-	-	3	0.2	-	-	7	0.4	3	0.1	2	0.1	3	0.2	-	-
<i>Filipendula</i>	2	0.1	2	0.1	1	0.1	1	0.1	-	-	1	0.1	-	-	2	0.1	-	-
<i>Artemisia</i>	13	0.4	21	1.2	2	0.1	11	0.5	8	0.3	11	0.8	8	0.5	19	1.3	52	2.5
<i>Urtica</i>	6	0.2	21	0.8	12	0.9	6	0.3	2	0.1	5	0.4	7	0.4	5	0.3	-	-
<i>Rumex</i>	43	1.5	71	4.1	37	2.6	94	4.0	40	2.1	48	3.5	92	5.7	62	4.2	37	1.7
<i>Chenopodiaceae</i>	5	0.1	20	0.8	6	0.4	5	0.2	3	0.2	4	0.3	3	0.2	6	0.4	24	1.7
<i>Caryophyllaceae</i>	2	0.1	-	-	1	0.1	4	0.2	-	-	1	0.1	1	0.1	2	0.1	-	-
<i>Cannabaceae</i>	7	0.2	1	0.1	5	0.3	4	0.1	2	0.1	3	0.2	1	0.1	2	0.1	6	0.3
<i>Plantago major</i>	-	-	-	-	-	-	1	0.1	1	0.1	1	0.1	-	-	1	0.1	4	0.2
<i>Plantago lanceolata</i>	-	-	10	0.6	8	0.5	15	0.4	6	0.3	9	0.7	11	0.7	13	0.9	9	0.4
<i>Centaurea cyanus</i>	2	0.1	2	0.1	1	0.1	2	0.1	-	-	2	0.2	4	0.2	3	0.1	10	0.5
<i>Cerealea</i>	87	2.5	139	5.1	75	5.2	95	4.4	32	2.1	37	2.7	101	6.2	74	5.0	156	7.2

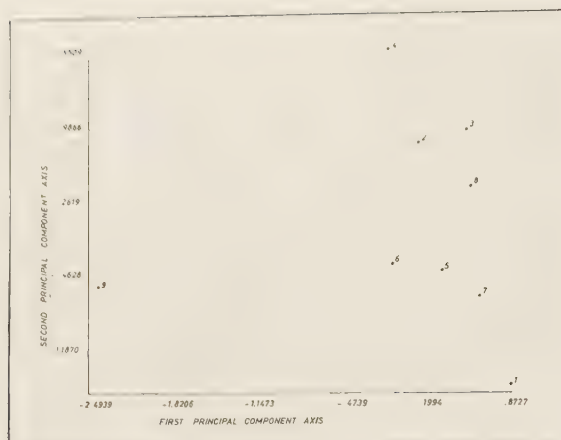


Figure 24. The comparison of the pollen spectra of the investigated lake sediments (the lake numbers are the same as in Fig. 24) using PCA. The samples are plotted on first and second principal component (55.4 % eigenvalue), using correlation matrix.

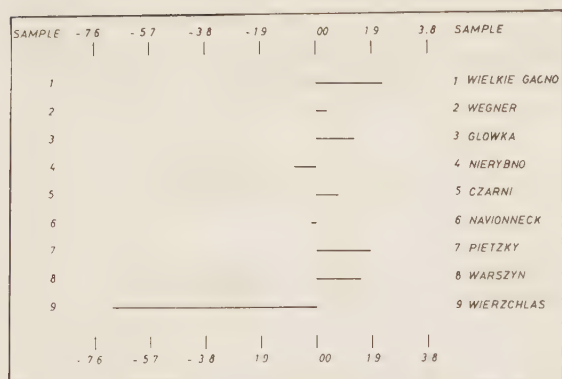


Figure 25. Stratigraphic plot of sample scores on principal component 1 (30.5 % eigenvalue) on the correlation matrix of 26 terriphytic spermatophytes from 9 different lakes.

4. Summary

All the lakes are situated in the same district, in the Tuchola pine forest. Wielkie Gacno, Głowska, Nierybno, Czarne, Nawionek, Piecki and Warszyn are surrounded by dense Pinus-forest and immediately on the lake shores each has a narrow belt of broad-leaved trees. Lake Wegner lies on the southern boundary of the Tuchola pine forest-region and the lake can be considered to be under relatively intensive human activity.

The profiles were collected from the deepest part of each lake and, because the lakes are of almost the same size, it is assumed that the possible sources of error are nearly the same in each profile. On the basis of the average percentage value for the three uppermost samples for each species the lakes are most easily compared with each other (Tabl. 6).

Even if it is not possible to compare all the fine details of the study, it is easy to see that the results of each lake are similar despite the prevalence of human activity around some lakes (cf. lakes Wegner and Warszyn). Moreover lake Wielkie Gacno can certainly be considered representative of that part of the Tuchola pine forest region.

IX. REGIONAL VEGETATION HISTORY

The reconstruction of the regional vegetation during the Late-Glacial and the Holocene has been made primarily on the basis of the percentage diagram taking into consideration, above all, the forest vegetation and plant succession (Figs. 26, 30).

In the interpretation each pollen zone has been described briefly while the pollen assemblage sub-zones have been discussed more thoroughly.

1. Late-Glacial

In previously published investigations the pattern of the Late-Glacial vegetation history is more or less the same as in central and northern Poland (Wasylikowa 1964, Tobolski 1966, Szafranski 1961, 1965, 1973, Kepczyński 1958, Ralska-Jasiewiczowa 1966).

During the "Older Dryas" the vegetation was tundra-like with an abundance of heliophyte herbs and shrubs. Szafranski (1973) and Wasylikowa (1964) found nutlets of *Betula* sect. *albae* from Wielkopolski national park and Witow, respectively proving that, besides the dominating *Hippophaë rhamnoides* vegetation, the tree birch was also present.

In the "Allerød" first a *Betula-Pinus* phase is found followed by a *Pinus*-phase. Simultaneous with the deteriorating climatic conditions the *Pinus-Betula* forest thinned out and a parkland tundra with *Artemisia* and other herbs became dominant. This period is called the "Younger Dryas".

Probably due to the imperfection of the pollen analyses only a few occurrences of *Juniperus*-pollen grains have been observed in many of the previous works.

In Fig. 21 the pollen assemblage zones for the Late-Glacial of Lake Wielki Gacno have been compared with the pollen diagram from Witow situated in the southern part of the Polish Lowland Region (Wasylikowa 1964) using pollen assemblage zones proposed by the present author.

In the following the interpretation of the Late-Glacial vegetation is made on the basis of the Wielkie Gacno A1 pollen diagram (Fig. 27).

Pinus-Cyperaceae pollen assemblage zone

(ca 12 000 - 11 000 B.P.)

Only the uppermost part of the zone is represented in the diagram. The frequencies of secondary pollen grains are very low providing evidence for the small amount of redeposited material. The post-glacial landscape had probably not yet begun to change. The high values of *Pinus* originate from long-distance transport as well as the low values of *Betula*. The vegetation was very open, soils which were not covered by water, were very moist with *Cyperaceae*, *Gramineae* and *Equisetum* plants. On the higher ground *Salix* was present and there were some *Artemisia* and *Saxifraga* communities forming a treeless tundra type of vegetation.

The isolated patches of *Betula pubescens* were probably situated not far from the investigation area. Because of the low number of samples from that zone it is difficult to interpret what the climate was like at that time, but most probably it was cold and arctic.

Pinus-Betula-Gramineae pollen assemblage zone

(ca 11 800 - 11 300 B.P.)

The vegetation was still open with a pioneer forest vegetation of *Betula*. In this birch forest were some *Populus*-trees, and patches of *Salix*, while *Thalictrum* and *Filipendula* played important roles. According to the macrofossil finds *Pinus* immigrated into the area during the first part of this zone. The dryer sandy soils were probably covered by scattered individual *Pinus*-trees and a heliophilous vegetation with *Artemisia*, *Helianthemum*, *Saxifraga* and *Juniperus*. In the middle part of the zone the curves of *Salix*, *Juniperus* and heliophilous plants fall to their lowest values during the whole Late-Glacial time. It is quite obvious that *Pinus* formed rather extensive forests and the light demanding vegetation could not survive on the same scale as before. NAP frequencies are as low as during the Holocene, only *Filipendula* reaches its highest values in the Late-Glacial growing with *Gramineae* and *Cyperaceae* on the wet places along the edges of melt-water streams.

During that time the glacier ice-lobes began to melt and organic sedimentation in the present Lake Wielkie Gacno started. The sediment changes to a compact algal gyttja and the indications are that the climate improved rapidly.

The date for this sediment change is 11,840 ± 110 B.P. (Lu-1678).

Simultaneous with the change of sediment from algal gyttja to clayey algal gyttja in the upper part of the zone the frequencies of *Juniperus* begin to rise. Herbaceous plants participate in greater numbers particularly *Artemisia*, *Gramineae* and *Cyperaceae* while *Thalictrum*, *Chenopodiaceae* and *Rumex* also show an increase. Some pollen grains of Dryas have been found. All these indicate a deterioration in the climate. *Pinus* gradually retreated southwards making room for the expanding *Betula* forest.

Juniperus-Gramineae-Artemisia pollen assemblage zone

(ca 11 300 - 10 000 B.P.)

This zone is characterized by a strong increase in *Juniperus*. The vegetation alternated from pine forest-associations to those of *Betula* mixed with *Pinus*. The heliophilous plants: *Helianthemum*, *Artemisia*, *Saxifraga* and *Dryas* continued to play an important role in the park-tundra vegetation. In the later part of the zone the climatic conditions were probably somewhat improved. *Betula* and *Pinus* formed more dense forests and *Pinus* extended once more to the area. Light-demanding vegetation gradually gave way to the forest vegetation.

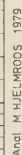


Figure 27. Relative pollen diagram WG A1 - the Late-Glacial part

In this sub-zone the Juniperus curve rises very rapidly. The date for the horizon where Juniperus increases is 11,380 ± 100 years B.P. (Lu-1679) but is thought to be too old (c.f. chapt. VIII). The Juniperus-rise can be related to the transition from the Allerød chronozone to the older part of the Younger Dryas chronozone.

Judging by the increase of in the amount of the herbaceous plants the climatic deterioration was probably quite marked. There is a layer of sand in the sediment, indicating that dune forming processes were active (cf. Tobolski 1966, Wasylikowa 1964). The NAP rise is due, above all, to the increasing values of heliophytes which must have grown on the sandy places surrounding the investigation area. On the dunes, the plant communities was probably formed by steppe elements (so-called cold steppe with Stipa Joannis) (Czubinski 1950). Juniperus, Artemisia, Helianthemum, Saxifraga, Rumex and Gramineae, among other light-demanding species, attain their Late-Glacial maxima. Betula nana pollen increases and a park-like vegetation must have formed on the places between dunes. According to the macrofossils Betula pubescens was also present, but forming, together with scattered Pinus-trees, a thinner forest than in the previous zone. The climate was quite cool, as indicated by the traces of tundra plants which have been found in the sediment (e.g. Dryas). The climatic conditions attained their maximum hardness in the upper part of the sub-zone.

Pinus-Betula sub-zone

At the sub-zone boundary the Juniperus curve begins to fall. This change is dated to 11,000 ± 100 B.P. (Lu-1681). The date is thought to be somewhat too old. According to the chronozone system proposed by Mangrud et al. (1974) such a date should correspond to the Allerød - Younger Dryas transition (see also Chapt. VII: discussion about the errors in the 14C-dates and the absolute chronology for the Late-Glacial). Here, however, the question is rather of the beginning of the climatic improvement and the transition from the Late-Glacial to the Holocene.

The amounts of tree pollen increase and the macrofossils show that Betula pubescens was growing on the place and in denser thickets than during the previous sub-zone.

NAP values rise slightly due to increasing Gramineae and Cyperaceae frequencies. This may be a reflection of the meadow-area growing around the modern Lake Wielkie Gacno as it was gradually released from the ice. There is no proof of the oceanity of climate: which is often connected with the corresponding stage in Western Europe, rather the climate seems to have been quite continental and dry.

Despite its decreasing tendencies Juniperus has high percentage values during the whole sub-zone. Towards the end of the sub-zone it has a transitory expansion and there is a new slight spread of steppe elements. There is also some evidence for the appearance of Ephedra distachya-type in this period.

The last expansion of Juniperus may be correlated with the Juniperus-rise recorded in Southern Scandinavia and Denmark during the transition from park-tundra vegetation to forest conditions (cf. Iversen 1954, Berglund 1966). This is thought to reflect a sudden climatic improvement during which Juniperus increased and spread more quickly than the trees and then declined dramatically when the more competitive trees came to occupy the land at the beginning of the Holocene. In NW Poland, however, Juniperus seems to have been the dominant species during the whole of the last cold phase after the Allerød chronozone.

2. Holocene

Pinus-Betula pollen assemblage zone
(ca 10 000 - 9 700 B.P.)

This zone is represented by two samples in the main pollen diagram. Using as support the near-shore pollen diagrams (WG B,A1,A2, A3), in which the Pinus-Betula zone is better recorded, the vegetational development can be interpreted as follows.

Pinus expanded quickly and it maintained its dominance on dry places and on dunes which had recently been formed. On the basis of the macrofossils pine was common and probably already formed large areas of forest. Betula has a short-term maximum which culminates in the upper part of the zone. Betula probably formed dense forests on the moister places where scattered Corylus and Ulmus trees also occurred. Juniperus had to retreat and disappear almost completely, as did other shrub- and dwarf-shrub vegetation. The presence of Artemisia, Rumex and Chenopodiaceae indicates that the soils were not yet leached, and that open communities were quite common. Meadow-birch wood communities may have predominated since grasses and sedges still remained common and Filipendula achieves its highest frequencies for the Holocene. Plantago media and Parnassia palustris, among others, could be connected with this meadow vegetation. The whole Wielkie Gacno lake basin was free of ice and sedimentation began even in the deepest parts of the lake. The climate was still cool but warmer than in previous zone. The presence of pollen grains of Typha latifolia indicate that the average July temperature was about +14 - 15 °C (Wasylikowa 1964).

Pinus-Betula-Corylus pollen assemblage zone
(9 700 - 8 925 B.P.)

The whole zone is dominated by Pinus and Betula.

The lower zone boundary is characterized by a sudden expansion of Corylus. Ulmus immigrates at the same time but is, as yet, shaded out by Corylus. Alnus immigrates and quickly expands in the later part of the zone. Juniperus still occurs sporadically, probably growing on the duneslopes where light conditions were good. The Salix observations may originate from shore vegetation. Ericaceae, which can be connected with the Pinus com-

munities is found in low frequencies. The low values of Artemisia and Rumex prove that treeless communities also existed, but, as a whole, the NAP curve has fallen since the previous zone.

Ulmus sub-zone (9 700 - 9 150 B.P.)

Pinus spread rapidly on higher places and sandy soils. It formed dense forests on dunes with Ericaceae in the herb-layer. On more fertile soils, where Betula dominated forests existed, Corylus expanded quickly, and formed forest associations with the birch.

Ulmus immigrated about the same time as Corylus, but, because of the rapid and strong expansion of the latter and its better competition-power Ulmus was held back and attained only low values. On the very best soils Ulmus was able to form smaller thickets, probably together with Salix and Populus. Quercus has frequent but low values through the whole sub-zone. It may have grown in the Ulmus patches or since the oak is more light demanding and would most likely have been checked patches or since the oak is more light demanding and would most likely have been checked by Ulmus it may have preferred the transition belt between the Pinus and Betula and Corylus-Betula forests.

The finds of Filipendula, Parnassia palustris and the continuing high values of Gramineae and Cyperaceae may originate from riverside and lakeside meadows.

Ulmus-Alnus sub-zone (9 150 - 8 925 B.P.)

Betula and Pinus remain virtually unchanged during this sub-zone but Corylus attains its highest values for the Holocene.

Alnus pollen grains had already been found sporadically in the preceding sub-zone but real spread of alder occurs at the beginning of this sub-zone. Alnus soon came to occupy the land along lakes and rivers. It has generally been thought that the expansion of Alnus was proof of a great improvement in climate and this event has been considered as the beginning of the "Post-Glacial Warm period". It is also assumed that the Alnus pollen grains in question are Alnus incana, which prefers organic deposits. This species has moderate trophic requirements but does not thrive on strongly acid soils. Because of the early arrival of alder in the investigation area it is of greatest interest and importance to determine which species it is. Unfortunately, though, it is impossible to separate the pollen grains of Alnus incana and Alnus glutinosa in fossil material. The possibility that Alnus glutinosa already occurred, at least as scattered individuals, cannot be eliminated. However, the Alnus thickets in which Betula and Salix occurred probably existed along lake shores and in fens. On the basis of the decreasing values of Gramineae and Filipendula one can suggest that the area of meadows may have been reduced, probably as a result of the expanding alder.

Pinus-Betula-Corylus-Alnus pollen assemblage zone (8 925 - 7 200 B.P.)

Pinus prevails with its dominance on sandy places, mainly dunes, growing. The rising Ericaceae curve shows that the pine forests were quite open. Betula probably had to give up some of its former area to other broad-leaved trees, while Alnus and Corylus developed rapidly.

Quercus expands at the beginning of this zone and soon attains as high values as those of Ulmus. Tilia and Fraxinus have already immigrated but are still too insecure to be able to struggle for living room against the more competitive tree species.

Ulmus-Quercus sub-zone (8 925 - 8 700 B.P.)

This short sub-zone demonstrates the expansion of Quercus which was perhaps, mixed in the Pinus forests on gently inclined slopes with southern exposures.

Quercus-Ulmus sub-zone (8 700 - 7 200 B.P.)

Pinus is temporarily forced back, mainly by Alnus and Corylus, in the beginning but its values soon rise again. Betula is slightly losing its importance. Perhaps it occurred only as smaller thickets on lake shores. In the middle and later part of the sub-zone Ulmus, which had occupied the very best soils, expands still further on the better soils replacing Corylus and preventing Tilia from expanding. However, Quercus comes to dominate over Ulmus during this sub-zone.

Alnus, probably Alnus incana, covered the moist places but decrease when soil leaching started and the soils became too acid. Alnus glutinosa had most probably expanded, having very likely already immigrated during the earlier part of the zone and spread during the middle part of the sub-zone.

A minor decline in the alder curve occurs in the later part of the sub-zone. This first decline of Alnus is said to be a characteristic feature for NE Poland during the "Boreal" period (Ralska-Jasiewiczowa 1966 and litt. cit. in). In NW Poland the decrease is found during the early Atlantic chronozone. The retardation may be explained by the north-eastern migration route of Alnus glutinosa. From another aspect the chronozones are not comparable, because of the lack of an absolute chronology in the earlier investigations.

The scattered finds of Mercurialis perennis must originate from the broad-leaved forest. Viscum pollen grains have also been observed.

It is quite obvious that the climate during the middle and later part of the sub-zone was dryer and warmer than before.

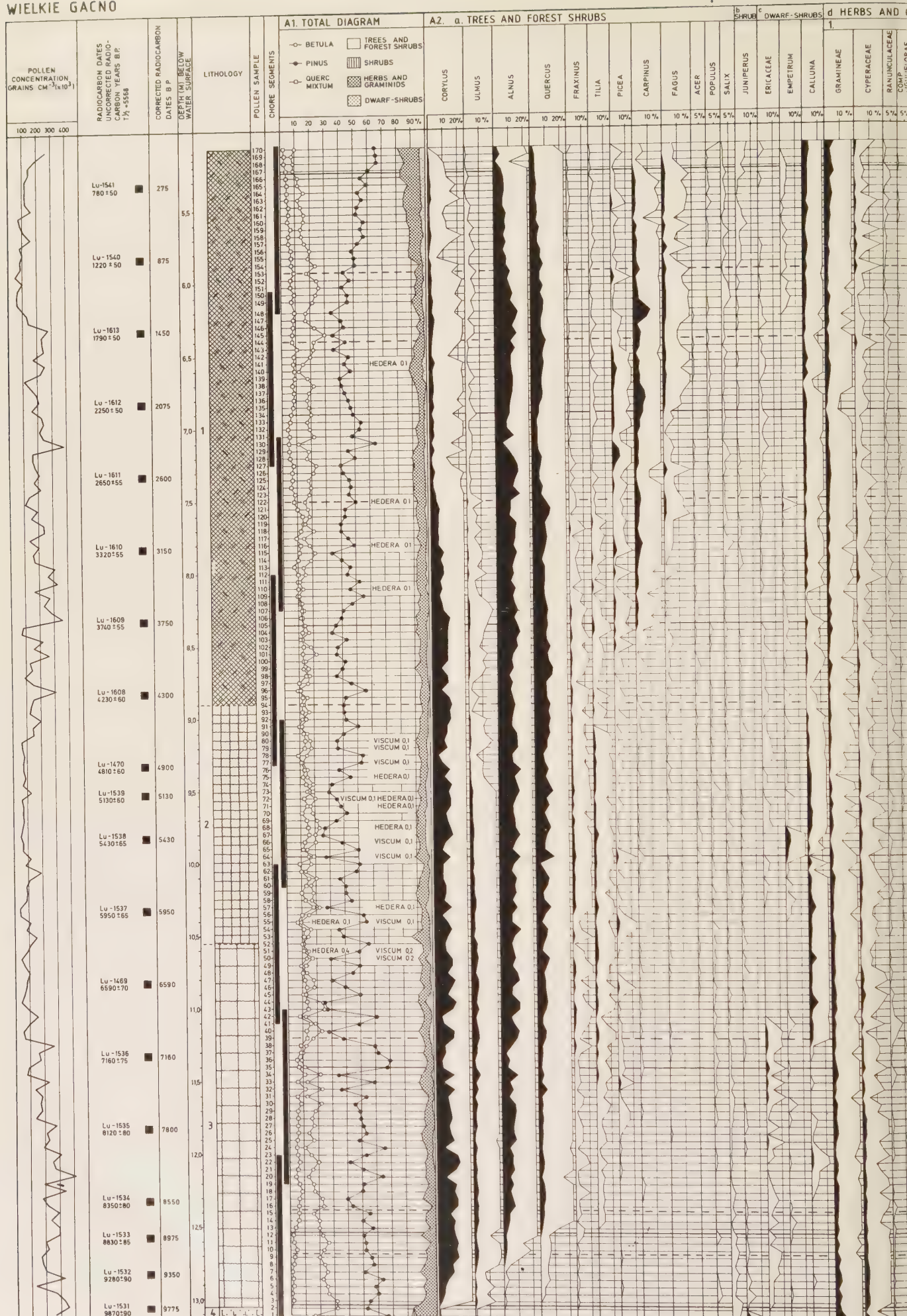


Figure 26. Relative pollen diagram Lake Wielkie Gacno - the main profile

Pinus-Betula-Corylus-Alnus-Ulmus pollen assemblage zone (7 200 - 5 500 B.P.)

The area of Pinus decreased. It was driven to the highest places where the soils were thin and poor, but preserved its dominance on dunes. Ericaceae type pollen is replaced by Calluna in the middle and later part of the zone, which quickly obtains quite high values indicating an open forest and communities rich in ling in the pine wood.

The zone is characterized by the spread of Tilia at the very beginning and that of Fraxinus somewhat later. All the nemoral broad-leaved trees had immigrated in the earlier part of the zone and through the competition for light and favourable soils the pioneer trees were forced back. A stable climax forest was established.

Quercus-Tilia sub-zone (7 200 - 6 950 B.P.)

In the beginning of this sub-zone there was a definite spread of Tilia in the investigation area. In the final phase of the preceding zone Tilia had already formed isolated stands on the favourable places, having probably taken over areas from Corylus. Hazel was restricted along the lake shores and the forest margins. Its proportion in the pollen flora does not, however, diminish noticeably.

Quercus-Tilia-Fraxinus sub-zone (6 950 - 5 500 B.P.)

This sub-zone stands for the time of the climax forests and the end of a great succession whereby the balance between several tree species was reached in a stable primeval forest. Fraxinus expanded in the beginning of this sub-zone, probably growing with alder on wet, fertile soils in narrow belts along streams and lakes. The ash, however, never achieved such a wide distribution as it did in western Europe at that time.

At the same level where the Ulmus frequencies diminished there is a marked appearance of Picea. The values are so high that it may be supposed to have grown in situ (1.5 - 2 %). This could be a question of a southern immigration of spruce, because it then disappears again for over one thousand years.

At the upper boundary of this sub-zone many pollen grains of Carpinus have been found (0.5 %). Most probably Carpinus was not yet growing in the district, not even as single trees, but the scattered hornbeam stands were most likely situated in the neighbourhood.

The appearance of Artemisia and Plantago major indicates that open communities existed while Melampyrum and Mercurialis perennis thrived in the woods.

In the middle part of the zone there are the first finds of Hedera; Viscum is also recorded. They are found only as scattered finds and perhaps the plants were quite uncommon in the area.

The investigation area is rather poor and the maximum frequencies of the nemoral broad-leaved trees are relatively low. They played their most important role in the investigation area during the middle Atlantic chronozone. Towards the end of the zone the values of the nemoral broad-leaved trees decreased slightly due to the possible arrival of prehistoric man. The unbroken curve of Plantago lanceolata begins at this time.

Pinus-Betula-Quercus-Corylus-Alnus pollen assemblage zone (5 500 - 3 725 B.P.)

Pinus dominates throughout the zone.

This zone represents the time when Quercus was the dominant species in the forests of the investigation area. The gradual acidification of the soils can be seen in the changing pollen values of several species. Tilia declines in the middle part of the zone as does Ulmus. However, elm increases again in the later part of the zone. Carpinus expands in the later part. Picea is also found, at fairly high values at the upper boundary of the zone. The pollen diagram discloses evidence for pasture and arable land indicated by the appearance of Plantago lanceolata, Junciperus, Rumex acetosella coll., Artemisia and by single Cerealia finds.

Ulmus-Tilia-Fraxinus sub-zone (5 500 - 4 325 B.P.)

Quercus is still increasing slightly at the beginning of this sub-zone. In the middle part, however, the forest ecosystem was disturbed; Ulmus declined distinctly but temporarily. The elm curve rises again but it does not attain as high values as before. At the upper sub-zone limit Ulmus disappears almost totally. A short time before the last Ulmus decrease Tilia declines, too. The causes of these sudden changes in the ecosystem are discussed more closely in the chapter "Human impact on the natural vegetation".

Quercus increases slightly after a temporary decrease simultaneous with the Ulmus-decline in the middle part of the sub-zone.

The increasing signs of pastures and arable land are characteristic for the second half of this zone.

Ulmus-Fraxinus sub-zone (4 325 - 3 725 B.P.)

This sub-zone is characterized by the regeneration of Ulmus. At the same time Quercus attains its maximum values for the Holocene. Due to the diminishing elm and lime stands the forests had very likely been more open on moister, better soils and near lakes which can be seen in the higher values of Alnus and Corylus. They had not necessarily expanded but their pollen dispersal increased.

In the upper part of the sub-zone the forests were replaced with the expansion of Carpinus and a slight rise in the curve of Picea, simultaneously increased human activity is observable in the area.

Pinus-Betula-Alnus-Carpinus pollen assemblage zone
(3 725 - 2 050 B.P.)

Pinus is the dominant tree species with pollen values increasing somewhat in the upper part of the zone. Betula shows a little expansion in the forests of the investigation area which were probably more open.

The zone is primarily characterized by the expansion of Carpinus, simultaneous with which all the nemoral broad-leaved trees show a successive decrease. Fraxinus declines at the beginning of the zone and both Ulmus and Tilia disappear in the middle part. Alder woods attain their maximum development during this zone. Fagus is found in low frequencies and it may already have formed small thickets. At the same time as Corylus decreases in the middle part of the zone, there is a temporary rise in the beech curve, but this is only short-lived. Simultaneous with the Carpinus-expansion there is an increase in the values of forest-herbs, Galium, Mercurialis perennis, Prunella-type, Melampyrum, which could be associated with the Carpinus-mixed forests. The increased utilization of arable land in the district is indicated by a new expansion phase in the later part of the zone. The unbroken Cerealea curve begins.

Quercus-Ulmus-Picea-Corylus sub-zone
(3 725 - 2 725 B.P.)

The increased expansion of Carpinus leads to a decrease in the nemoral broad-leaved trees. As a result of climatic deterioration and partly also due to human activity Tilia and Fraxinus disappear almost totally in the later part of this sub-zone and Ulmus occurs only as single trees. On the richer soils with good edaphic conditions Carpinus and Quercus formed forests, while on the dryer and poorer soils Quercus mixed with Betula and Pinus, was most common.

Near lake shores and in places with stagnant water Alnus forests occurred, being adjacent on one side with the Carpinus-Quercus woods, where individual Fagus trees and stands may also have existed.

Quercus-Picea sub-zone (2 725 - 2 050 B.P.)

This sub-zone is characterized by the maximal values of Picea and Alnus. Corylus shows a distinct decrease at the beginning of the sub-zone, Quercus values are slightly depressed during the whole sub-zone. It is quite probable that Picea took over areas from Carpinus in connection with the human activity. The reciprocal development of hornbeam and spruce may be a function of the increase in cultivated land in the region.

Pinus-Betula-Alnus-Carpinus-Fagus pollen assemblage zone (2 050 - ca 100 B.P.)

Pinus is dominant but in the early part of the zone pine-pollen values decrease slightly. Coincident with the start of the last human activity expansion phase Pinus rises distinctly, indicating perhaps the opening of the landscape. The expansion of Pinus may reflect more intensive cultivation and thus a greater dispersal of pine pollen. In the later part of the zone, when the values of the other tree pollen types decrease Pinus was very likely planted in the area and the modern Bory Tucholskie gradually began to form. The former cleared areas must have been extremely poor before the large pine plantations were started (e.g. Hausendorff 1941). These wooded lands were probably used extensively for grazing. In the pollen diagram this is seen in increasing values of Empetrum, Calluna and Juniperus.

The most outstanding feature for this zone is the expansion of Fagus. Beech was already sparsely present during the Pinus-Betula-Alnus-Carpinus zone but only in this zone does it reach this greater scale, perhaps as a result of climatic deterioration and/or the greater area of grazed forests. Fagus is a light-demanding tree and in grazed forests it could expand without any greater impediments. In this part of Pomerania, however, Fagus never acquired, as wide a distribution as in Central Europe. In the early and middle part of the zone Carpinus attains its highest values, and Alnus and Quercus increase slightly. In the later part all the broad-leaved trees decrease in favour of strongly increased Pinus values. Picea disappears during the early part and at the present day is very rare in the Tuchola pine-forest area.

Quercus-Picea sub-zone (2 050 - 1 500 B.P.)

Even at the beginning of this zone Fagus probably formed smaller forests occurring on soils with good drainage. The Lonicera found during the beginning of this period may originate from the shrub layer of the beech and/or oak forest. Carpinus forests mixed with Quercus seems to reach their greatest distribution.

Corylus falls below 3 % and loses its importance in the forests on the moister soils. Instead the values of Betula and Alnus increase. The appearance of Picea is still connected with human activity.

Quercus sub-zone (1 500 - 925 B.P.)

This sub-zone is characterized by low values of Picea at the very beginning. From this point, spruce is encountered only sporadically and most likely it disappeared totally from the region. Alnus and Carpinus reach their last maxima during the Holocene simultaneous with a decrease in the amount of pine.

The last expansion phase of human activity starts in the upper part of the sub-zone with a strong increase in the anthropochores and apophytes.

In the beginning of this sub-zone the NAP values rise distinctly, and there is also a rise in Pinus frequencies, testifying to the intensified exploitation of the landscape. Changed edaphic conditions coupled with decreased atmospheric humidity may have caused the reduction of Alnus with this species surviving only in the water-lodged places. In the later part of the zone, when the cultivated soils were degraded, they may have been used as pastureland.

Pinus pollen assemblage zone (ca 100 - B.P.)

During this zone the Tuchola Pine-forest district assumed its modern character. The vegetation is totally dominated by Pinus, Carpinus, Fagus and the other broad-leaved trees have disappeared. Only Alnus and Quercus remain in favourable places. The greater part of the district was planted with Pinus-forest. The number of species in the herb layer is small and mostly composed of Vaccinium sp. and a large number of lichens.

3. Pollen influx data

The influx values for different AP species mainly follow the respective curves in the percentage pollen diagram. When the profile is dominated by one species, as here by Pinus, the absolute influx values can often be a good support when interpreting the insignificant and low percentage frequencies of other species. The pollen influx diagram of Lake Wielkie Gacno is illustrated in Fig. 28.

In the lower part of the diagram the total AP influx values vary from 10,000 grains $\text{cm}^{-2} \text{yr}^{-1}$ to about 25,000 grains $\text{cm}^{-2} \text{yr}^{-1}$. At the boundary between the Early Atlantic and Middle Atlantic chronozones the tree pollen influx values decrease noticeably to around 5,000 grains $\text{cm}^{-2} \text{yr}^{-1}$ and only temporarily reach values of over 10,000 grains. During the lower part of the Early Sub-boreal chronozone the influx values rise over 10,000 and at the beginning of the Middle Sub-boreal chronozone the maximal values of over 25,000 grains $\text{cm}^{-2} \text{yr}^{-1}$ are found. The influx rate of AP remains around 15,000 - 20,000 grains up to the middle part of the Middle Sub-atlantic chronozone, where it decreased dramatically by c. 15,000 grains to c. 5,000 grains $\text{cm}^{-2} \text{yr}^{-1}$. In the upper part of the Subatlantic chronozone the total AP influx values slightly increase to the recent values of 17,000 grains $\text{cm}^{-2} \text{yr}^{-1}$.

Because of the low number of NAP-grains the curve of the total pollen influx values is generally parallel with that of AP-grains. Herbs and graminids during the Pre-boreal and Early Boreal chronozones have values of 1,500 - 2,000 grains $\text{cm}^{-2} \text{yr}^{-1}$, after that generally 500 grains. Simultaneous with the local anthropogenous phases (see Chapt. X) the influx rates of NAP increase by over 1,000

grains reaching, however, only temporarily values of over 2,000 grains.

The pollen influx-diagram for the Holocene shows four main phases in the total pollen influx:

- high values during the Pre-boreal, Boreal and Early Atlantic chronozones,
- low values until the beginning of the Early Sub-boreal chronozone,
- high values up to the middle part of the Middle Sub-atlantic chronozone, and
- low values during the uppermost part of the profile.

(In the most recent sediments the influx values show an increase due to the strongly risen pollen influx values for Pinus.)

The decrease at the chronozone boundary Early/Middle Atlantic can be explained fairly easily. It is thought that when forest associations have reached their climax stage, the denseness of the forest probably effectively prevents pollen dispersal.

At the beginning of the Early Sub-boreal chronozone the influx rates for NAP increase slightly and about 4,700 B.P., almost simultaneous with the finds of the first Cerealea pollen, influx values of AP increase strongly. Pinus is still dominant but Betula, Corylus and Alnus seem to increase clearly, perhaps the forests were more open and the good light conditions favoured the dispersal of the pollen of those pioneer species growing in cleared areas. These species are also considered to be heavy pollen producers.

One possible explanation may be the changed barymetric and morphologic conditions in the lake basin and its surroundings. These may be caused by large-scale variations in the vegetation cover mainly because of the altered soil conditions.

It is evident that the humidity increased and the level of groundwater rose. That caused changes in the vegetation as well in the lake itself (see the further discussion in Chapt. XII).

The influx diagram indicates, as does the percentage pollen diagram, that the human impact has been rather slight but more or less continuous up to A.D. 700. The effect of human activity upon the natural vegetation in the investigated area is seen mainly by the increased pollen influx rates. There is seen an increase of the taxa, too (Fig. 29). That is supposed to be caused by the opening of the landscape. It is surprising, however, that the influx rates are so even in spite of the fluctuations in the human activity.

At the depth of 6.50 m, in the upper part of the 5th local anthropogenous phase, in the middle part of the Middle Sub-atlantic chronozone, Corylus and Betula rise and slightly afterwards also Alnus and Carpinus as an assumed evidence of the deforestation. Simultaneous with the short-time rise in the influx values of Alnus and Carpinus the rates of all other species decrease dramatically. It could be possible that land use in the investigation area was so intensive that the tree species as well as the herbs and graminids did not have enough time to produce pollen before being destroyed by man (similar case cf. Huttunen 1980). However, it seems that this is a real decrease, as that time is very poor in terms of historical factas.

Perhaps the temporarily changes sedimentation rate, which is impossible to notice because of the incomplete ^{14}C -datings, caused that change in the influx frequencies. It is also conceivable that the changes in soil conditions (e.g. prolonged leaching) caused a drop in productivity and thus a decrease in the production of pollen grains (c.f. Moore 1968).

It has to be stressed that each of the

POLLEN INFLUX - DIAGRAM. WIELKIE GACNO



Figure 28. Pollen influx diagram Lake Wielkie Gacno only selected pollen taxa (number of grains $\text{cm}^{-2} \text{yr}^{-1}$)

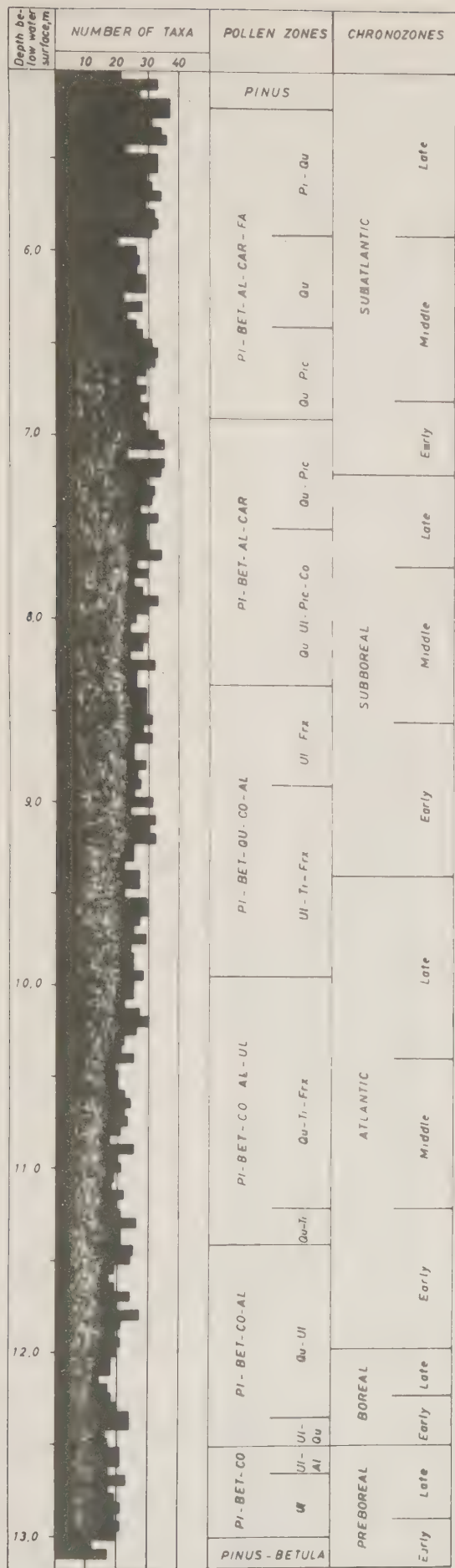


Figure 29. Number of taxa during the Holocene, Lake Wielkie Gacno.

changes in the pollen influx rate during the Holocene has probably been the result of many different effects, both climatical, edaphical and anthropological which alone and/or together have influenced the natural vegetation. Influx values are low up to A.D. 1400 and after that Pinus frequencies increase successively, reaching the recent values of 17 000 grains in the uppermost samples. The Pinus rise is most probably due to the pollen production from the Pinus forests planted in the investigation area. Similarly plantations are documented in some other areas in Central and NW-Poland (Hausendorff 1941, Czubiński 1947). The values of other AP and NAP are very low.

4. Remarks on the main features in the vegetation development

Late-Glacial

The development of the late-glacial vegetation communities in the Lake Wielkie Gacno area seems to have been fairly typical of Central and Northern Poland and Northern Central Europe.

The pollen analytical results prove that during the Allerød Chronozone the polar forest was situated to the north of the present Tuchola Woods. Pinus immigrated in the earlier phase of the Allerød and then expanded rapidly. Even during the cool period, the Younger Dryas chronozone, forests existed in the area, although the tree cover was thinner than before. The open forest was formed primarily of Betula trees with the less frequent Pinus being situated mainly in sheltered favourable places.

The vegetation of the Younger Dryas Chronozone was strongly dominated by Juniperus communities.

Holocene

The main forest succession started in the earlier part of the Pre-boreal Chronozone. As soon as climate amelioration had begun Pinus occupied the high places and Betula spread out onto the low-lying moist places. The steppe-like communities and those areas of late-glacial herb and shrub communities were gradually restricted during the transition from the Younger Dryas to the Pre-boreal Chronozone and, to some extent, already during the later part of the Younger Dryas Chronozone.

After the dead-ice had melted away and the landscape began to attain its Holocene structure meadow communities developed along the rivers and lake-shores as well as on wet places between the dunes. The pollen composition of the herbaceous plants indicates meadow communities of the Molinietalia type, which mostly grow on a mineral substratum. There have most probably been associations like Filipenduleto-Geranium palustris from the order Molinietalia in the district (Libbert 1932 in Pawłowski 1966).

In the later part of the Early Pre-boreal chronozone Corylus expanded and occupied those soils with a thicker mull layer where neither Pinus nor Betula could threaten its spread (c.f. the corrected AP diagram for the Holocene in Lake Wielkie Gacno, Fig. 30). Hazel, which also thrived in the open Pinus-Betula forest demands a moderate shade, but was never as common there as in those areas which lacked other more competitive shade trees. In this area of Pomerania Ulmus arrived at the same time as Corylus. Although Ulmus has a longer life-span than Corylus, its growth rate is particularly low during youth and it was thus easily smothered by Corylus. Elm could find unoccupied spaces and occasionally hindered the spread of hazel. It was probably Ulmus glabra, which is less warmth-demanding than the other Ulmus species, which arrived first in the district. It succeeded in occupying the very best soils and consolidating its position there before Tilia, later on during the Atlantic Chronozone gradually took them over. As mentioned before, it is thought that Alnus incana immigrated from the south during the final phase of the Pre-boreal Chronozone. It played an important role in flooded places and could form forest communities perhaps mixed with Ulmus (cf. Ulmus laevis) which immigrated at time that climatic conditions changed for better. Ulmus laevis and Ulmus carpinifolia can both grow on wet places and tolerate flooding.

The expansion of Quercus also took place at the beginning of the Boreal Chronozone.

It is very difficult to try to reconstruct the forest communities during the older part of the Holocene. There may have been great differences between the life amplitude and ecological demands of the tree species at that time and those of today.

However, it may be supposed that during the Boreal and the Early Atlantic Chronozones the drier, sandy soils with unfavourable habitats, mostly on higher places were occupied by Pinus sylvestris. The pine forests were mixed probably with Betula and Quercus. Unfortunately it has been impossible to separate out the different species of oak in the pollen analyses but it is obvious that both Quercus robur and Q. petraea were present. They seldom formed pure stands but were mixed with pine, alder and ash. Quercus petraea thrives today on sandy soils and was then probably growing with Pinus on dune slopes. On more moist soils Quercus robur was competing with Ulmus for growing space. As the soils changed to become richer and moister the forests became Ulmus-dominated with an admixture of Alnus and Corylus. A few Tilia and Fraxinus trees may have occurred in the Ulmus forest on the most fertile soils. Along rivers and lake shores and on flooded habitats Alnus (cf. A. incana), Betula perhaps with Salix and Populus formed thickets with a distinct nitrophilous herb layer (Cannabaceae, Compositae and Urtica).

In the middle and the lower part of the late Atlantic Chronozone competition between several species seems to have led to the established climax forest. Lime and ash also found their places in this balanced forest. According to the corrected tree-pollen diagram Tilia, Fraxinus, Ulmus and Quercus all played an important role in the Quercetum mixtum forests in the investigation area.

The lime was for the most Tilia cordata, only a few pollen grains of T. platyphylla have been found. Pinus was pressed to the extremely poor places with a high degree of permeability. In richer stands Ericaceae

(incl. Calluna) may have been the dominant species in the herb and shrub layer. Soils had probably become partly podsolized.

On the richer sands acidophilous oak-pine forest was common. The proportion of pine may have been quite small and the stands were dominated by Quercus mixed by Betula and Tilia cordata. The shrub layer seems to have been rather poor and formed primarily by young plants of broad-leaved trees including Corylus avellana. Pteridium aquilinum is thought to have been abundant in these forests.

On fertile ground numerous kinds of deciduous forests developed, mostly with nemoral broad-leaved trees as the dominant species. The most common of these may have been the associations of elm mixed with Tilia, Fraxinus and Quercus. The old fluvial deposits, rich in nutrients, probably supported elm carrs. These changed to alderash carrs in places which were periodically flooded. The soils of the alderash carrs were also rich in nutrients but had a more mineral substratum than these of the elm carrs. The herb layer in the Fraxinus - Alnus dominated forests seems to have been rather dense with Urtica, Filipendula, Cannabaceae (cf. Humulus), Chrysosplenium, Compositae and Filicales, amongst others.

Corylus avellana stands were restricted to the forest margins and along lake shores.

In the final phase of the Late Atlantic Chronozone oak, lime and even ash seem to have a slight retrogressive development. Probably the climate became more humid which led to increased leaching of the soils and their gradual degradation. Elm reacted somewhat later to these probable deteriorations in living conditions.

Prehistoric man seems to have begun to exploit primarily those Quercetum mixtum forests situated in the richer soils. Coincident with the thinning and decrease in area of the nemoral broad-leaved forests Corylus seems to take the role of a pioneer species again. In those forests Betula also expanded, but this new pioneer phase was just a temporary one.

The dominance of the Fraxinus-Alnus dominated forests on rich, moist places continued into the sub-boreal chronozone. These frequently flooded soils were seldom utilized by man as arable land. On the contrary, they may have been used as a grazing land because of their luxuriant herb layer. Acer is also found in small amounts in the pollen flora and probably belonged to alder-ash associations.

In the Middle Sub-boreal Chronozone the forest composition altered noticeably. In the first place, this may have been due to edaphic factors (see e.g. Andersen 1971). Soils in the investigation area were largely poor sandy ones and leaching in such soils is very fast (see e.g. Daubenmire 1974). Throughout this deterioration the soils became more acid. In the nemoral broad-leaved forests the changed conditions were most beneficial to Quercus.

On sandy habitats the composition of the forest communities became gradually stabilized. The acidophilous Quercus - Pinus associations were attaining their modern structure.

Prehistoric man took advantage of the better soils and probably first destroyed the Ulmus - and Tilia communities. At the same time the climate became a little cooler and dryer and some new species began to expand into the area. Ulmus and Tilia were unable to recover their former significance after the forest clearances. Picea and Carpinus,

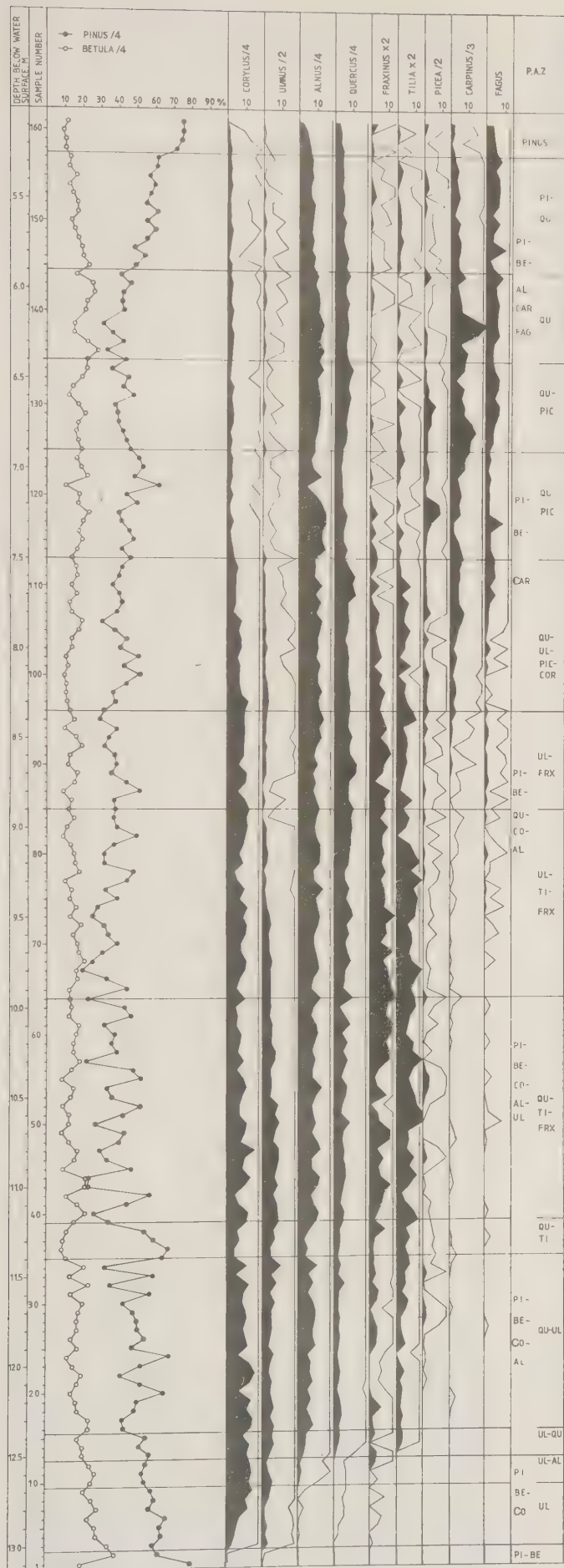


Figure 30. Corrected AP percentage diagram Lake Wielkie Gacno (Correction acc. Anderson 1973).

Immigration of tree species in northern Poland

which had occurred sporadically, seem to have had established themselves as soon as farming became less intensive. Oak may have held its ground in spite of the ecological and human disturbances. Communities corresponding to the modern *Querco-Carpinetum* developed. *Ulmus* has the same light-demands as *Carpinus* but the latter has a wider soil-tolerance when both soil acidity and soil moisture are taken into account. Elm and lime were gradually suppressed. Simultaneously with the *Carpinus* depressions and slightly after the anthropogenous phases *Picea* expanded into the *Quercus* forests but later gave way to the more competitive *Carpinus*. The herb layer in such forests seems to have been rather rich. Besides grasses, *Ranunculus*, *Potentilla* and *Galium* are also found. Above all, soil moisture contributed to the luxuriance of the herbs (c.f. Fig. 29).

In the Middle Sub-atlantic Chronozone *Corylus* seems to have disappeared and lost its importance as a tree on wet places, along river sides and lake shores. That happened principally to the advantage of *Fagus*. According to the pollen diagram *Fagus* seems to have expanded into the investigation area about 1500 years later than *Carpinus*. The area may have included extensive pastures and grazed forestlands which gave beech all the opportunities to spread. *Fagus* mainly occupied the fertile soils being bounded on the upper side by *Pineto-Quercetum* associations and on the lower by *Querco-Carpinetum*. Beech attains the eastern limit of its occurrence in Poland and therefore is often mixed with *Querco-Carpinetum* associations today.

However, it may be supposed that there were some smaller beech stands in the district corresponding to the modern *Fagetum boreoatlanticum* community (Pawłowski 1966). Here *Fagus* may have been mixed with *Quercus*, *Carpinus* and *Pinus* as secondary trees. *Lonicera xylosteum* probably belongs to the shrub layer of this forest type. From the herb layer *Mercurialis perennis* should be mentioned in particular. *Alnus* maintained its important role along flooded lake shores and river banks even during the Sub-atlantic Chronozone.

In the later part of the Late Sub-atlantic Chronozone increased humidity and, more especially the exploitation of arable land resulted in an accelerated erosion and leaching of soils and thus a reduction in the nutrient capital. In the investigation area those soils which even under natural conditions were poor, could no longer serve as agriculture land but were grazed and gradually employed for forestry.

The forest communities were formed largely artificially and *Vaccinium myrtilli-Pinetum* was the most common one. The composition of the shrub layer was rather poor: most frequently the young plants of the deciduous trees occurred, mainly *Quercus* and *Betula*. The herb layer was also sparse the dominant species being *Vaccinium myrtillus* and *Vaccinium vitis-idaea*.

In accordance with the moisture and richness of the soils several alliances occurred: *Leucopryo-Pinetum*, *Peucedano-Pinetum*, *Vaccinio uliginosi-Pinetum*. Along lake shores, in water-logged places *Alnus* and *Fagus* formed smaller stands.

As discussed earlier the boundaries between the pollen assemblage zones and pollen assemblage sub-zones have been drawn mainly on the basis of the immigration order of the forest trees. The chronological development of the forest trees in the Lake Wielkie Gacno region is shown in table 7. Comparing the Wielkie Gacno pollen diagram with other Polish pollen diagrams has proved difficult because there are only a few reliable 14C-dates available, those from northern and north-eastern Poland.

Averdieck (1978) has a 14C-date for the rational *Corylus* limit from NE Germany which is nearly the same as that for the present investigation area. In northern Poland, from Zarnowiecie Lake, M. Latałowa's investigations, however, give an age for the *Corylus* limit which is nearly 700 years younger (9065 ± 65 B.P.). In Denmark this limit has been dated to 9750 - 9650 B.P. (Hafsten 1970) and in southern Sweden to 9590 B.P. (Nilsson 1964). Thus the immigration of *Corylus* in the early Holocene seems to have been virtually simultaneous for the whole of northern Central Europe. The later spread of the hazel into the northernmost part of Poland is due to the vicinity of the Baltic.

It is interesting to observe, too, that the immigration of *Corylus* took place only about 150 years later in Southern Sweden than in the investigation area, which means that *Corylus* spread very quickly through the whole of northern Central Europe into Southern Scandinavia.

The rational limit of *Ulmus* is of the same age as that of *Corylus* in the Wielkie Gacno area. In a pollen diagram from Woryty, NE Poland (Pawlikowski, in print) *Ulmus* seems to have immigrated simultaneously with *Corylus*. Unfortunately this part of that diagram has not yet been dated. The results from Lake Mikołajki show a somewhat earlier *Ulmus*-immigration in comparison with *Corylus*, but this profile has not been dated either (Ralska-Jasiewiczowa 1966). In the dated pollen diagrams from N-Poland (M. Latałowa, in print) and NE-Germany (eg. Averdieck 1978) the rational *Ulmus*-limit is about 500 years younger than in the Wielkie Gacno area. It is thought that elm immigrated from the east.

The very early occurrence of *Alnus* is interpreted, as mentioned earlier in this paper, as the immigration of *Alnus incana*. It is generally held that *Alnus* spread from the east in to northern Central Europe (cf. Andersson 1897). According to Hyypä (1933) and Thomson (1929) *Alnus incana* was found during the Late-glacial in South-eastern Finland and above all on the southern shore of the Baltic. It has also been expressed by Koperowa (1962) that some refugia of *Alnus* (and other thermophilous trees) existed in the SW Carpathians. It may be possible that the *Alnus incana* in the Wielkie Gacno pollen diagram originates from these Late-Glacial occurrences.

Whatever the reason the rational *Alnus*-limit here is about 1000 years older than in N-Poland and NE-Germany. In Southern Sweden the limit has been dated to 8500 B.P. (Nilsson 1964) and in SE-Sweden to 8840 B.P. (Berglund 1966). If it is a question of an

Table 7. Corrected 14C-ages (using the graphically fitted time-depth curve of Fig. 19) for the most important events in the development of the forest trees, excluding *Betula* and *Pinus*, (B.P.).

CORYLUS:		FRAXINUS:	
- rational limit	9750	- empiracal limit	9000
- first maximum	9150	- rational limit	6900
- last decrease	2800	- disappearance	3650
ALNUS:		PICEA:	
- empirical limit	9600	- first occurrence	7350
- rational limit	9150		6000
- first decrease	7550	- rational limit	4000
- last decrease	1250	- maximum	2400
		- decline	1650
ULMUS:		CARPINUS:	
- rational limit	9750	- empirical limit	5000
- first maximum	6950	- rational limit	3800
- first decrease	5450	- first maximum	3150
- "elm-decline"	5050	- second "-"	2800
- second increase	4800	- third "-"	2000
- second decline	4450	- fourth "-"	1350
- final decrease	2800	- decline	300
QUERCUS:		FAGUS:	
- empirical limit	9550	- empirical limit	5150
- rational limit	8950	- rational limit	2050
- last decrease	900	- decline	300
TILIA:			
- empirical limit	8750		
- rational limit	7150		
- decline	4300		
- disappearance	2850		

early immigration of *Alnus incana* in the Wielkie Gacno diagram, it is difficult to calculate the age of the rational limit of *Alnus glutinosa*, nevertheless it is assumed to be at around 8000 - 8200 B.P.

The expansion of *Quercus* took place more or less simultaneously with that of *Alnus* in several places in Poland and NE-Germany as well as in Danemark (Szafranski 1961, 1965, 1973, Kepczynski & Noryskiewicz 1968, Ralska-Jasiewiczowa 1966, Pawlikowski, in print, Latałowa, in print, Nilsson 1948). It looks as though *Quercus* had immigrated somewhat earlier in most places but the real expansion of oak occurs some hundreds of years later than that of alder in Southern Scandinavia. In the Wielkie Gacno area the immigration of *Quercus* is delayed by about 200 years in relation to that of *Alnus*. The same holds true in the results of other investigations from Tuchola Woods (Mielczarek & Brykalski 1931, Kepczynski 1958).

Due to the rather low frequencies of *Tilia* it has been difficult to draw its rational limit in the Wielkie Gacno diagram. The same problem seems to occur in other pollen diagrams from central Northern and Central Poland (Kepczynski 1958, Szafranski 1961, 1973). Latałowa's (in print) investigations from Zarnowieckie, N-Kashubien, prove a distinctly earlier immigration of *Tilia* (14C about 7800-7900 B.P.). Averdieck (1978) has a date of 8250 B.P. from NE-Germany and Nilsson (1964) 7950 B.P. from Southern Sweden, thus indicating an 800 - 1000 years earlier spread of *Tilia* to these areas. These results confirm the information on the map in Firbas (1949, p. 179) according to which *Tilia* occurred more abundantly in Southern Danemark, NE-Germany, NE-Poland and in the lowland

area northward of the Alps and Carpathians than in Central Poland and in Central Northern Poland.

Spruce immigrated into Poland from two directions: as early as the end of the Late-Glacial from the Carpathians northwards and during the "Boreal time" into Northern Poland from the north-east. It was thought that as a result of human activity *Picea* was not able to spread into the Middle-Polish area. It has been proposed eg. by Srodon (1967) that *Picea* has never occurred in the Tuchola Woods-district. That area is considered to belong to the Middle-Polish spruceless belt (Jedlinski 1922). In spite of these arguments it seems to be quite obvious that *Picea* did occur in the investigation area about 2000 years ago. Its appearance was, indeed, heavily pressed down by man's destructive activity in the forests of the area (see also Kepczynski 1958). Nor is it impossible that the relatively high frequencies of spruce in the Atlantic Chronozone have had their origin in the *Picea*-stands spreading from the south.

Although *Carpinus* spread into Poland from the east its rational limit is approximately the same in Woryty, NE-Poland and in the Wielkie Gacno area (4155 + 65 B.P. and 3900 B.P. respectively. There is thus only about 150-200 years delay in the immigration. From Zarnowieckie Latałowa has an approximate age of 3200 B.P. (in print). Further to the west *Carpinus* became scarcer and its immigration was delayed by some thousands of years: the rational limit is found for the most first after the birth of Christ.

The investigation area lies rather close to the eastern boundary of *Fagus* in Central Europe. Most probably it has spread into the area from the north-west along the great river valleys. This would explain why the expansion of beech in the Wielkie Gacno area was delayed by about 600 years in comparison with NE-Germany and Southern Scandinavia where the unbroken *Fagus*-pollen curve begins much earlier: in NE-Germany about 4500 - 5000 B.P. (Tapfer 1940, Averdieck 1978), Danemark about 4500 B.P. (eg. Troels-Smith 1937) and in Southern Sweden 3800 - 4000 B.P. (Nilsson 1935). Even in the Wielkie Gacno diagram sporadic finds are recorded from 5150 B.P. and there is an earlier occurrence of beech (about 2800 B.P., 1.5 - 2.0 %) about 700 years before the rational limit and the real expansion of this tree.

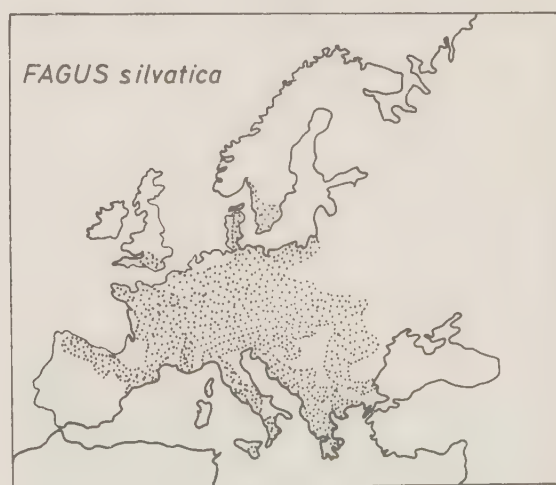


Figure 31. The modern distribution of *Fagus* in Europe

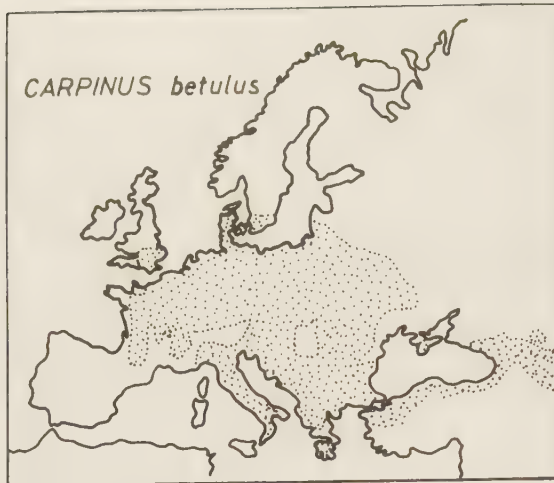


Figure 32. The modern distribution of Carpinus in Europe

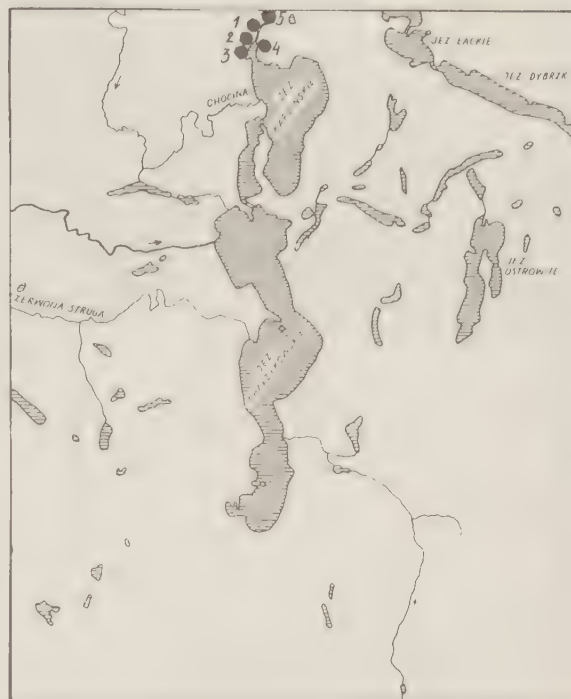
X. HUMAN IMPACT ON THE NATURAL VEGETATION

1. The archaeological background of the area investigated

Because of linguistic difficulties it has been impossible to delve deeply into the available archaeological literature. The only modern study from the district around Lake Charzykowskie is that of G. Wilke (1978) which deals mainly with Medieval times and the period immediately preceeding it. All pre-historic information is based on scattered finds and scattered notices. No archaeological excavations have been carried out in the area so far, but according to information from the archaeological institute in Toruń interest in this part of the Tuchola Pine-forest district is now great and the possibility of excavations will be considered.

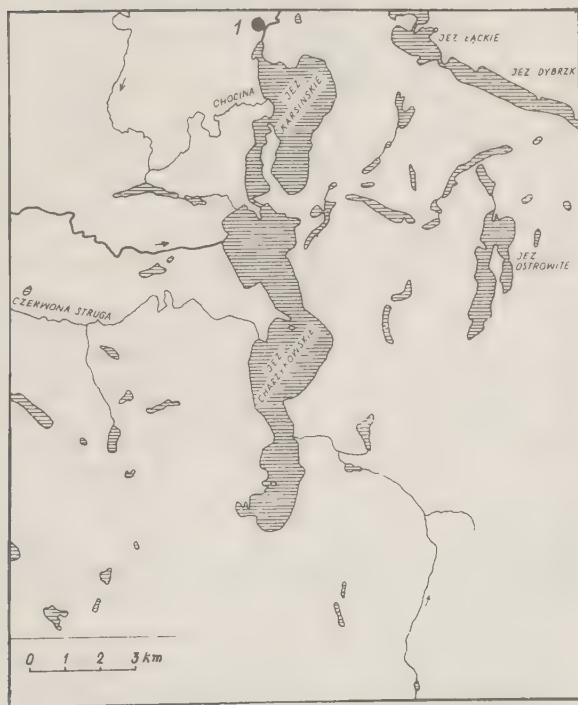
Here the history of the settlement in the area is presented in the form of maps (following discussion with G. Wilke) (Fig. 33 a.h.).

(According to Renfrew, 1976, b.c. have been used instead of B.C.).



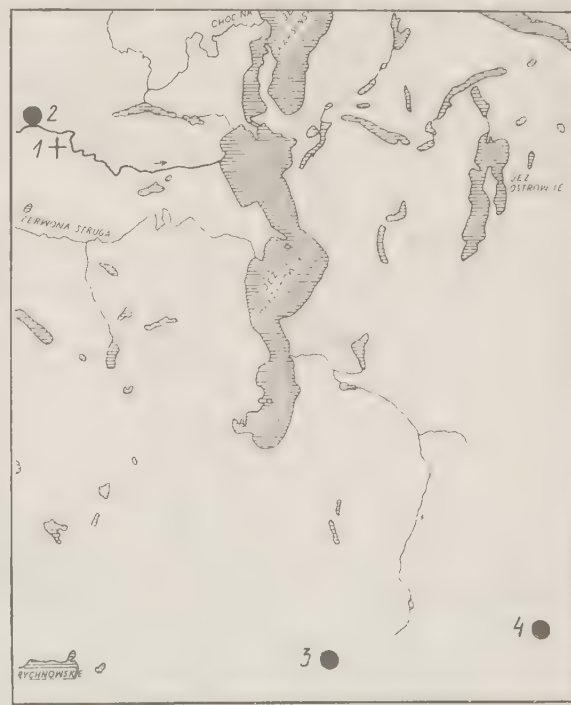
b. The Mesolithic II (6 000 - 5 000 b.c.)
- the chojnicko-pieńkowska culture

1. Swornigacie: 200 fragments of flint tools from an area of 180 m²
2. Swornigacie: scattered finds
3. Swornigacie: scattered finds
4. Swornigacie: scattered finds
5. Swornigacie: scattered finds



a. The Mesolithic I (7 500 - 6 000 b.c.)
- the komornicka culture

1. Swornigacie: 25 fragments of flint tools from an area of 35 m².



c. The Neolithic
- the middle Neolithic (3 500-2 500 b.c.)
- the late Neolithic (2 500-1 700 b.c.)

1. Cicholewy: a grave field
2. Konarzyny: scattered finds
3. Nierzychowice: scattered finds
4. Pawłowo: scattered finds



d. The Bronze Age (1700–650 b.c.)

1. Chojniczki: coins with Lusatian motif (1200–1000 b.c.)
2. Swornigacie: scattered finds with originate in the Trzciniec culture (1450–1200 b.c.)

4. Chojnice: a grave field from the early and middle La Tène period (400–125 b.c.).
5. Chojnice: scattered finds from the beginning of the Hallstatt period (650–500 b.c.).
6. Chojnice: a grave field from the Hallstatt period (650–400 b.c.).
7. Chojnice: a grave field from the later part of the Hallstatt period (500–400 b.c.).
8. Chojnice: a grave field from the Hallstatt period (650–400 b.c.).
9. Chojniczki: scattered finds from the latter part of the Hallstatt period (500–400 b.c.).
10. Cicholewy: a grave field from the Hallstatt period (650–400 b.c.).
11. Dolina: scattered finds from the Hallstatt period.
12. Jarcewo: a grave field from the early and middle La Tène period (400–125 b.c.).
13. Jarcewo: scattered finds from the Hallstatt period.
14. Jarcewo: scattered finds from the Hallstatt period.
15. Konarzynki: a grave field from the Hallstatt period.
16. Konarzynki: a grave field from the Hallstatt period.
17. Konarzynki: a grave field from the Hallstatt period.
18. Pawłowo: scattered finds from the later part of the Hallstatt period (650–400 b.c.).
19. Pawłowo: scattered finds from the Hallstatt period.
20. Pawłowo: a grave field from the Hallstatt period.



e. The Iron Age (650–125 b.c.)

– the East-Pomeranian group

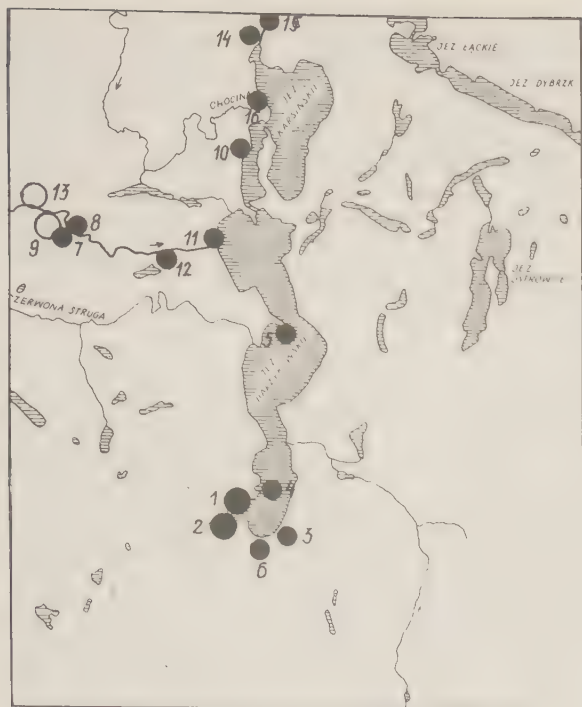
1. Charzykowy: probable dwelling site from the Hallstatt period (650–400 b.c.) and from the early La Tène period (200–250 b.c.).
2. Charzykowy: probable dwelling site from the Hallstatt period.
3. Charzykowy: probable dwelling site from the Hallstatt period.



f. The Younger Roman Time (0–A.D. 350)

- Konarzyny: a grave field
- Pawłowo: a grave field

N.B. There are no finds from the later La Tène period (125–0 b.c.), neither from the older part of Roman Time or the Migration period (A.D. 350–600).



g. The Early Medieval Period (A.D. 600-1300)

1. Charzykowy: a fortress from the 9th-10th centuries.
2. Charzykowy: a fortress from the 8th-10th centuries.
3. Charzykowy: a settlement from the 10th - 13th centuries.
4. Charzykowy: probable settlement from the 9th-13th centuries.
5. Charzykowy: probable settlement during the whole of Early Medieval Times.
6. Charzykowy: settlement during the whole of Early Medieval times.
7. Cicholewy: settlement from the 8th-10th centuries.
8. Cicholewy: settlement from the 10th-13th centuries.
9. Cicholewy: a possible fortress from the 10th-13th centuries.
10. Kokoszka: settlement from the later part of Early Medieval Times.
11. Kopernica: settlement from the 8th-12th centuries.
12. Kopernica: settlement from the 8th-12th centuries.
13. Salpolno: a supposed fortress from the 9th-12th centuries.
14. Swornigacie: settlement during the whole of Early Medieval Times.
15. Swornigacie: settlement during the whole of Early Medieval Times.
16. Swornigacie: settlement from the 9th-10th centuries.



h. Colonisation during the 12th-15th centuries

1. a central town from the 12th-13th centuries
2. a town from the 14th century.
3. notices about a settlement from the 12th - 13th centuries.
4. notices about a settlement from the 14th - 15th centuries
5. an Augustine monastery (founded A.D. 1272).
6. lake
7. cultivated soils
8. partly cultivated soils
9. uncultivated soils

Figure 33. a-h. Maps showing the history of settlement in the area investigated (9 500 - c 400 B.P.)

2. Traces of Mesolithic settlement

On the basis of the pollen diagram it is difficult to say if there was any human activity in the Wielkie Gacno region before 3900 b.c. Throughout the whole of the Holocene the pollen spectra were dominated by *Pinus*, and small-scale clearances caused by hunters and gatherers would, obviously, have had only a slight effect on the total pollen composition.

One has a feeling that something has

happened to the natural vegetation during the Early Atlantic chronozone. One pollen grain of *Plantago major* is found together with a slight maximum of *Artemisia*-, *Urtica*-, *Rumex*- and *Cannabaceae*-pollen. The curve of *Pteridium* started to rise earlier. The *Pinus*-curve shows some disturbances but otherwise the pollen frequencies of the AP species are regular. *Picea* has a slight decrease at this point, increasing again quite

quickly. All this happens at the 1150 - 1160 cm level in the main pollen diagram. It is dated to about 5500 - 5400 b.c. and may be connected with some scattered finds around the northern part of Lake Karsinskie. It is thought that there was a seasonal dwelling place on the shore used by the people of the chojnicko-pieńkowska culture. It is possible that these hunters and fishers extended their activity to the Wielkie Gacno region which is situated about 10 km to the south of the find sites of the mesolithic artefacts.

3. Traces of human activity during the last 6000 years

a. Local anthropogenous phases

Human impact on the landscape is traced in the pollen diagram by the occurrences of hemerophilous plants (terminology after Simmons 1910, Linkola 1916 and Ahti & Hämet-Ahti 1971) and by disturbance in the forest ecosystems. Using primarily the frequency changes of the anthropochores and apophytes, it has been possible to identify six expansion phases in the human landscape (cf. Königsson 1968, Berglund 1969), (Figs. 34,35,37).

Phase 1. (3900 - 3500 b.c.)

The appearance of the first pollen grains of Plantago lanceolata and increasing values of Plantago major, Artemisia and Chenopodiaceae must be considered as a result of human activity. The regular finds of Calluna and Juniperus may indicate grazing. In terms of the forest vegetation an opening of the tree canopy is assumed, in that Betula, Corylus and Populus, as light demanding species, have slight maximum while Pinus values are low. As evidence of fire some Vicia-pollen are found together with increasing values of Pteridium (e.g. Berglund 1966, Göransson 1977).

Archaeologically this phase corresponds to the middle part of the Early Neolithic.

Phase 2. (3150 - 2650 b.c.)

The first Cerealea pollen is found at a depth of 950 cm coincident with the Ulmus decline. The surface pattering of the grain was like that of Triticum, but the pollen itself was so corroded and split that a precise identification was impossible. This level is 14C dated to 3100 b.c. Plantago lanceolata increases somewhat later together with Rumex, Urtica, Artemisia and Umbelliferae. The first Triticum pollen are observed at a depth of 915 cm and, in addition to Triticum, a pollen grain of Hordeum is also found (see Fig. 37). In the middle part of the period Pinus increases by about 20 % while Betula, Corylus and Alnus (the latter only in influx terms) are increasing slightly. This, together with high percentages of Pteridium and the occurrence of Vicia-type pollen provide evidence of slash-and-burn cultivation.

The maximum of Calluna in the earlier part of the period and higher values of

Juniperus in the later part can be considered as evidence of grazing. In addition to grazing, agriculture was actually practised during this period in the neighbourhood of the lake. This is shown by the presence of Cerealea pollen together with the pollen of plants which are considered as followers of man and indicators of cultivation. If Cerealea pollen are found alone, then the long-distance transport of these pollen must be considered.

Archaeologically this phase 2 corresponds to the Middle Neolithic.

Phase 3. (2000 - 1500 b.c.)

The lower part of this phase is characterized by a clear and sudden increase in Carpinus and thus a change in the composition of the forest. The pollen of Picea are found in such frequencies that one can suppose that spruce appeared locally. Soon after the Carpinus expansion an increase in human activity is seen in the form of grazing activity in the district. Both the percentage and influx values of tree pollen are high but there is also a distinct increase in human indicators: Artemisia and Cannabaceae, Chenopodiaceae and Rumex, and increasing Cerealea.

In the middle and later part of this period Carpinus and Quercus values decrease. Picea has a brief maximum but also decreases later. Betula and Corylus are increasing, and at the same time pollen grains of Epilobium and Vicia - type are found, while the Pteridium curve shows a maximum. Populus and Melampyrum benefited from the more open forests.

Archaeologically this period may be correlated with the transition Late Neolithic/Bronze Age as well as with the early Bronze Age.

Phase 4. (800 - 400 b.c.)

In the later Bronze Age Ulmus, Tilia and Fraxinus decline dramatically, Carpinus decreases, and at the same time there is an increase in Pteridium, Gramineae, Plantago lanceolata and Rumex as evidence of forest clearance. This forest clearance is followed by a short but intensive phase of human expansion with increased values of Triticum and Secale pollen. Together with high values for the indicators of human interference one pollen grain of Linum is found for the first time.

From an archaeological point of view this period may be correlated with the late Bronze Age and the Hallstatt C- and D- as well as the earlier part of the La Tène period.

Phase 5. (A.D. 150- 400)

Carpinus is decreasing while the influx values of Betula, Alnus and Quercus are high and slightly increasing. Gramineae and Calluna show a maximum and all grazing indicators are well presented. Cerealea, which besides Triticum also includes a large number of Secale pollen, has a distinctly marked increase. Some single pollen grains of Centaurea

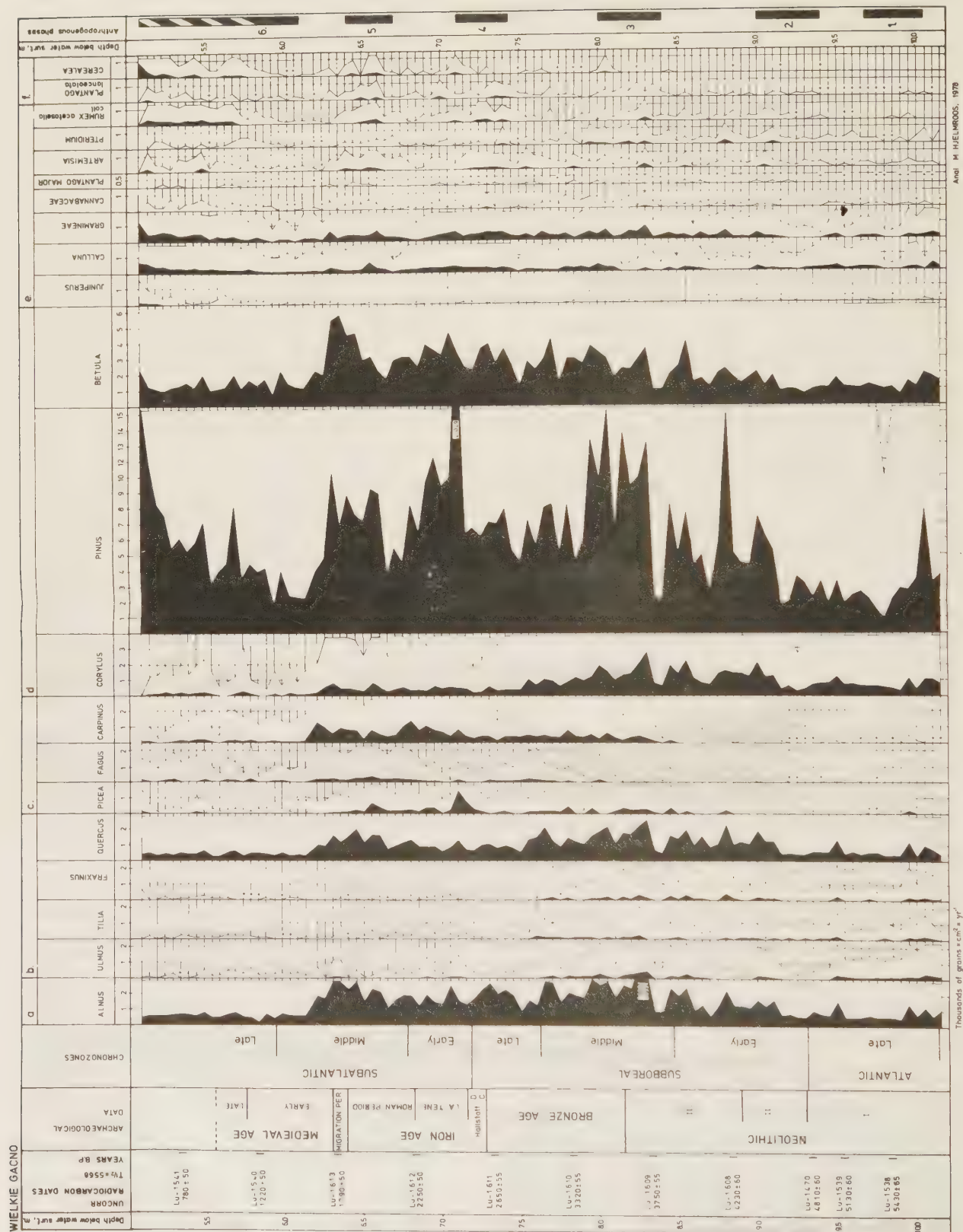


Figure 35. Special pollen influx diagram showing the human impact on the landscape (Lake Wielkie Gacno).

And. M. HELMROOS, 1978

cyanus are observed. In the later part of the period the curve for Carpinus begins to rise, reaching its peak at a depth of 620 cm, only to fall to very low values in the following and final phase.

This phase corresponds archaeologically to the middle and later part of the Roman period and the beginning of the Migration period.

Phase 6. (A.D. 750 -)

In fixing the lower boundary of this stage one can observe the importance of the pollen influx diagram in connection with studies of landscape changes and human activity. The dramatic drop in the influx values of all the AP species has no correlative in the pollen percentage diagram.

Throughout this period the landscape is more open and the proportions of herbs and grasses are increasing. The NAP reach a maximum and among them weeds show a marked increase. Besides Cerealea, Fagopyrum is also found in such amounts that it may have been grown in the close vicinity of the lake.

Archaeologically the beginning of this last phase corresponds to the middle part of Early Medieval Times.

Later on the landscape changed from one of cultivated arable land to grazed woodlands and open pastures with Juniperus and heaths. The last enormous expansion of Pinus caused by plantations occur only some hundreds of years ago.

In the surface sample Cerealea is found in its highest frequencies although no cultivation is practised in the surroundings of the lake. this is possibly because the uppermost pollen spectrum does not correspond to the present-day vegetation but rather to that at the beginning of this century.

b. Discussion and conclusions

During the Atlantic chronozone, before human activity had caused any wide-scale changes in the natural vegetation, the forest was composed of deciduous, broad-leaved trees, although the associations were dominated by Pinus. Several species of the different plant communities were competitive and demanded fertile soils.

During the early and middle part of the Neolithic I pollen grains indicating pasture occur simultaneous with a slight reduction in the nemoral broad-leaved forest. On the basis of the pollen finds of both apophytes and anthropochores such as Plantago lanceolata, Juniperus, Plantago major, Artemisia and Chenopodiaceae the opening of the forest is presumed to have been caused by man rather than forest fire. These Late Atlantic changes in vegetation may have been caused by tribes belonging to the Danubian culture, who, it is assumed, already practised some animal husbandry.

The first expansion phase (3900 - 3500 b.c.) has a pollen-analytical character similar to the earliest landnam phase in Denmark, sometimes called A-landnam (Troels-Smith 1953, 1961; Berglund 1969). It is, however,

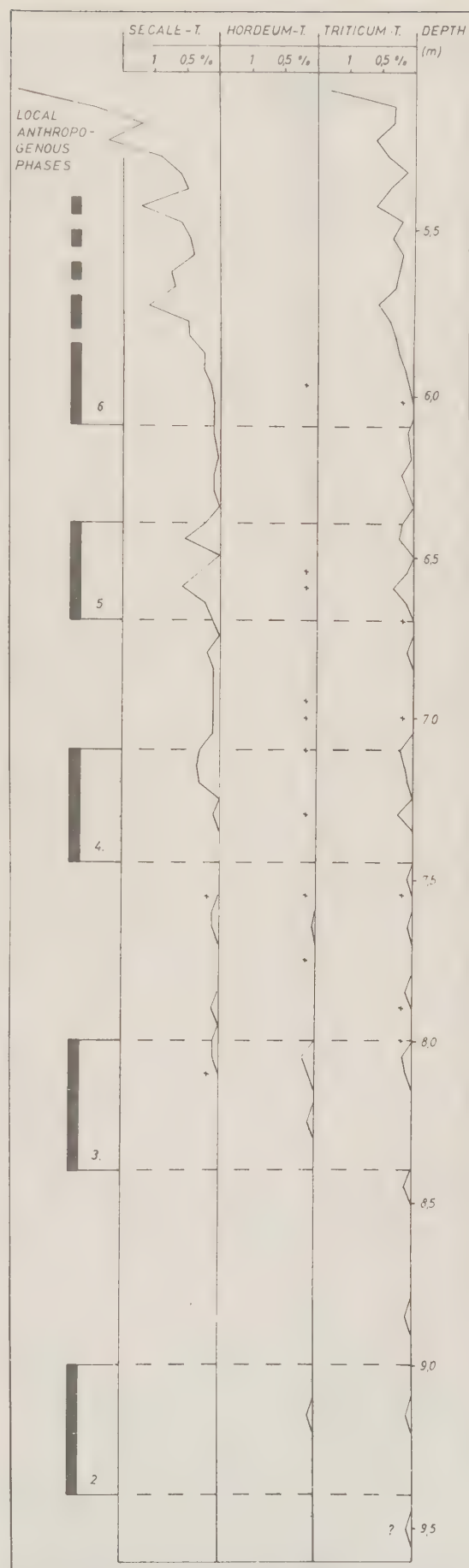


Figure 36. Diagram showing the appearance of different Cerealea species in Lake Wielkie Gacno sediment.

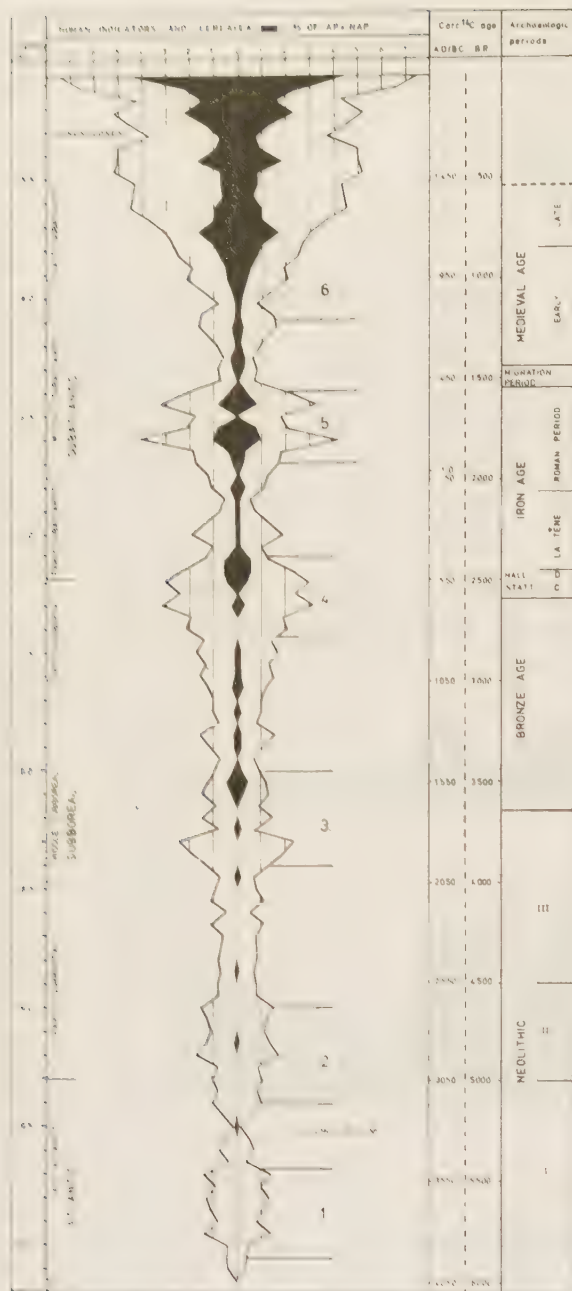


Figure 37. Human impact diagram with the local anthropogenous phases, (Lake Wielkie Gacno). Human indicators = groups d4 & d5 in the main pollen diagram.

more than 500 years earlier in the Wielkie Gacno area. Possibly this early phase can be correlated with the first introduction of stock-raising. Small areas were cleared to provide grazing land in the forest. There is no evidence of agriculture during this phase. Just after the *Ulmus* decline (about 2500 b.p.) in the later part of Late Atlantic there is a marked minimum of *Quercus* is observed simultaneous with a distinct increase in pollen rains of hemerophilous plants, indicating increased human activity with pasturing and stockraising. Somewhat

after that, about 2800 b.c. the first identifiable pollen grains of *Cerealea* have been found. (The very first *Cerealea* pollen is found at the same level as the *Ulmus* decline.) These *Cerealea* pollen are identified to *Triticum* sp. and one to *Hordeum*-type. This part of the Tuchola pine forest is poor in archaeological investigations, but at the Neolithic dwelling site of Chełma, near Toruń, *Triticum*, *Secale* and *Hordeum* are all found as macroscopic plant remains (Klichowska 1972). close to Lake Charzykowskie, on its western shore, there is a Neolithic grave field, and scattered finds of Neolithic age have also been found south of Lake Charzykowskie (Wilke 1978). The evidence of the *Cerealea* and *Plantago lanceolata* finds in the Wielkie Gacno - pollen diagram suggests that these neolithic people practised farming at the beginning of the Early Sub-boreal chronozone, which corresponds archaeologically to the Neolithic II. The percentage pollen diagram shows that this phase is comparable with the B-landnam (Iversen 1941) characterized by a minimum of *Ulmus* and *Quercus*, a simultaneous increase in the values of human indicators such as *Plantago lanceolata*, and quite high values of *Betula*. In the pollen influx diagram the minimum of the AP species is more distinctive and their increasing values in the later part of the period can be seen more clearly than in the percentage diagram.

Many different interpretations have been presented concerning the *Ulmus*-decline, debating whether it was caused by human interference or by a change in climatic conditions. A lot of these suggestions have been treated in a discussion by Göransson (1977). In the pollen diagram from Wielkie Gacno one cannot see any clear connections between the *Ulmus*-decline and human activity. Before the decline human influence is quite strong in the form of grazing causing a reduction of the broad-leaved trees. This is observed in decreasing values of the other QM-species: *Quercus*, *Tilia* and *Fraxinus*. *Ulmus* first declines somewhat later. Slightly after the *Ulmus*-decline human activity increases markedly and pollen finds indicate both arable land and pastures. The *Ulmus* reduction was possibly caused by edaphic and climatic changes leading to a situation which was immediately utilized by man.

Around the Late Neolithic/Bronze Age boundary, in the Middle Sub-boreal chronozone (2000 - 1500 b.c.), the next expansion phase is observed. The forest association has been developing into a form corresponding to that of the present *Quercus* - *Carpinetum* association. AP values decrease slightly in percentage terms, but the influx values show a distinct increase. However, in both diagrams the curve for *Carpinus* falls. *Carpinus* has been shown to be very sensitive to human activity and decreases simultaneously with the colonization phases (Ralska-Jasiewiczowa 1964, 1977). Probably this period was one of a more local character, and the traces of an enlargement of the area under pasture land and stock-raising, together with the cultivation of *Triticum*, *Hordeum* and probably also *Secale*, the pollen of which are found in the sediment, originated from the activity of people living directly in the neighbourhood of the lake.

The landscape was more open because of forest clearance caused partly by fire and partly by the use of leaf-fodder. The dominance of *Pinus* pollen is possibly due to long-distance transport.

The increase in the clearance of fields for cultivation is also reflected in the amount

of mineral material washed into the lake basin, which can be observed in the loss-on-ignition curve as well as in the increasing values of Isoetes. It has been shown in England (Pennington 1975) that Isoetes cannot tolerate increased silting in the sediment and the amount of Isoetes spores decreases simultaneously with an increase in mineral matter. On the other hand Göransson (1977) has evidence for a connection between the maxima of the Isoetes and Pteridium curves. Pteridium is an indicator of forest fire which usually results in stronger erosion from the surrounding area into the lake. Vuorela (1980) has proved in Southern Finland that the appearance of Isoetes microspores is a valuable indicator for the beginning of human activity in the surroundings of a lake when appearing together with additional signs of human action. In the Wielkie Gacno profile the curve for Isoetes closely follows that of the mineral matter in the sediment.

The more open landscape seems to have provided suitable conditions for the spread of Picea into the area. Spruce, however, decreases as soon as the other more competitive tree species begin to regenerate.

During the middle part of the Bronze Age there was a slight stand-still in the degree of human influence. The pollen evidence indicates an open Querco-Carpinetum forest with grazing. Human activity is observed throughout the period, but not as strongly as in the earlier part of the Bronze Age.

In the Sub-boreal chronozone which, archaeologically, corresponds to the later Bronze-Age and the Hallstatt period, Carpinus has a new minimum which is followed by an increase in pollen grains indicating grazing and an enlargement of the area of arable land. There is an intensive expansion phase, dated to 800 - 400 b.c. with a large number of Cerealea pollen. According to Helbaek (1960) Linum was brought from Russia through the Baltic to Central Europe. Seeds of flax have been found at Biskupin together with finds of the Lusatian culture, corresponding to the Late Bronze Age and the Hallstatt period (Kozłowska 1966, Klichowska 1972).

The archaeological information from the Charzykowskie lake district indicates that the shores of the lake were rapidly and densely colonized, about 650 - 125 b.c., by people belonging to the Lusatian culture (Wilke 1978 and pers. comm.).

Simultaneous with the Cerealea maximum Picea is found in such large quantities that it was probably growing at that time in the Wielkie Gacno district. It has generally been held that Picea did not occur in the Tuchola pine forest during the Holocene or it has, at least, been relatively uncommon (e.g. Srodon 1967). Fragments of Picea excelsa have, however, been found in a soil sample from archaeological excavations at Odry, not so far from Wielkie Gacno (Klichowska 1969). This settlement site was in existence during the La Tène-period (La Tène: 400 - 0 b.c. - in the Wielkie Gacno region 500 - 100 b.c.). It is obvious that here also prehistoric man encouraged the advance of spruce with his clearance activities. Vera Markgraf has evidence from Switzerland, of how Picea, as a less sensitive tree species, came to dominance after forest clearances (Markgraf 1970).

Picea has a distinct decline slightly after the beginning of forest regeneration. Carpinus reaches its maximum around the boundary Early/Middle Sub-atlantic chronozone, and Quercus is also increasing.

The Querco - Carpinetum forest association seems to have reached its climax at this

time. The pollen diagram shows that cultural development has been continuous, but slight. It is perhaps worth mentioning that at Odry traces of ploughing and slash-and-burn farming have been found from this time (Kmicinski 1968).

During the Roman period (A.D. 50 - 400) Carpinus has a distinct minimum, during which Cerealea has two peaks, around A.D. 100 and 350. Simultaneous with the increasing proportions of Triticum and Secale-type pollen single Centaurea cyanus pollen are found which show that Secale was cultivated in the neighbourhood.

It has been emphasized by Lange (1971) that at that time in Poland Secale cereale was cultivated in as large amounts as Hordeum vulgare with Triticum aestivum taking third place in importance. When comparing Poland with Central Europe one can deduce that Secale must have moved from the east through Poland to Central Europe.

From an archaeological point of view the period between A.D. 100 and A.D. 350 is quite poor in finds from the area around lake Charzykowskie, but two grave fields.

The presence of man is clearly seen in the pollen analytical evidence, especially in the increasing NAP influx-values. Clearance took place presumably in the Querco-Carpinetum forest association, and the opening of the forest is indicated by an increase in the curves of heaths, Gramineae and hemerophilous plants. A new slight Picea-expansion is also noticed.

The Roman period is followed by a regeneration phase lasting from A.D. 500 to 750. The signs of settlement disappear almost completely. Pinus decreased, but still remained a dominant tree species, and the mosaic of a rather dense broad-leaved forest was probably quite common.

The sudden change in the pollen diagram at a depth of 620 cm dated to ca A.D. 750 cannot be explained as forest clearance caused by man. A distinct reduction can be noted in both all the AP-species and all the pollen grains indicating human activity. This problem is discussed in more detail in connection with the investigations of the regional vegetation history and those of water-level changes in Lake Wielkie Gacno.

Archaeologically this corresponds to Early Medieval Times. Following this, at a depth of 600 cm, dated to ca A.D. 975, a distinct increase in human influence is seen, especially in terms of the agricultural indicators: cereals, among which Secale is dominant, Fagopyrum and Cannabaceae.

At about A.D. 1300 the landscape picture changes slightly. Grazing elements become more common and the forest community turns into an association resembling Pineto - Quercetum. During the Sub-atlantic chronozone, when the temperature remained fairly constant and precipitation was quite high, soil conditions must have changed rapidly. Soil leaching which had already begun in the Sub-boreal chronozone continued. Valuable substances from the uppermost layers were washed downwards and the soils became less fertile and poorer in nutrients (e.g. Berglund 1966).

Some smaller fluctuations in Cerealea and the human indicator-curves are seen. In the later part of the 18th century and at the beginning of the 19th century the last forest clearance occurred, the enormous Pinus expansion after this clearance is caused by plantations of this tree (pers. comm. in Torun and e.g. Hausendorff 1941). At the same time the forest association changes to a Vaccinio - Pinetum association and on the moister soils to something like a Leucopryo - Pinetum. Very little written

material is available about forestry in the Tuchola pine-forest district. According to Hausendorff (1941), who has made detailed investigations of forestry in the western part of present-day Poland, forest plantations began in the early part of 16th century (around 1550). By studying old maps and notices he demonstrated that Quercus and Betula were favoured as filling-in vegetation for the Pinus-plantations. The plantations were renewed about every 200 years.

XI. WATER-LEVEL CHANGES

This investigation is based on the macrofossil analysis of four profiles, which have been correlated pollen-analytically. Three profiles, A1, A2 and A3 have been taken along one line out from the NW-shore. The distance between the different profiles was chosen so that in the outermost profile only slight water-level changes would be registered. The fourth profile, B1, was taken from the innermost part of the western bay.

The situation of the profiles is shown in Fig. 17.

The field work and the methods used in the macrofossil and pollen analyses are described in Chapt. IV. The stratigraphy of the investigated profiles is described in Chapt. V.

1. Description of the pollen diagrams

The pollen diagrams will be described only in their main features, paying particular attention to possible hiatuses in the zone sequences. However, only those hiatuses, where the whole pollen assemblage zone or sub-zone is lacking are observed. It is quite obvious that there are several smaller hiatuses which are difficult to observe in the profiles A1, A2 and B1 the pollen of the local vegetation disturb the interpretation to some extent. Sometimes *Pinus* is found considerably over-represented in such shallow-water sediments (e.g. Digerfeldt 1974). Here, however, the *Pinus* frequencies are, to a great extent, of the same order as in the main pollen diagram from the central part of the lake with the exception of diagram B1, where *Pinus* occurs in very high values. The uppermost part of the sequence is lacking in all the profiles. the uppermost *Sphagnum*-peat in A1, A2 and B1 has not been analyzed. In each case the peat was underlain by water. At the sampling point B1 the uppermost sediment was so loose that it was impossible to collect with the Livingstone sampler. At A3 the bottom may be situated above the present sediment limit.

Pollen diagrams WG A2 and WG A3 (Figs. 37 and 38)

Except in the uppermost part these diagrams are well developed and represent an unbroken Holocene zone sequence.

In the A2 diagram the *Pinus*-*Betula* PAZ and in both diagrams the *Pinus*-*Betula*-*Alnus*-*Carpinus* PAZ in particular are compressed. Most of the zone boundaries are easily distinguished, although sometimes the interpretation is done partly on the basis of the NAP. In the A3 diagram *Pinus* appears to be quite unstable and a certain over-representation of *Betula*, *Alnus* and *Corylus* is seen. Pollen curves for species with low frequencies, such as *Fraxinus*, *Tilia*, and *Picea* resemble those in the main diagram. In both diagrams the *Pinus*-*Betula*-*Quercus*-*Corylus*-*Alnus* PAZ, the *Pinus*-*Betula*-*Corylus*-*Alnus*-*Ulmus* PAZ and the *Pinus*-*Betula*-*Alnus*-*Carpinus*-*Fagus* PAZ are the most detailed and extended.

Pollen diagram WG A1 (Fig. 39)

In this diagram most of the pollen assemblage zones are very compressed and two clear hiatuses can be established. The oldest one is found immediately at the beginning of the Holocene, including the *Pinus*-*Betula* PAZ and the lower part of the *Pinus*-*Betula*-*Corylus* PAZ. Above this hiatus *Corylus*, *Ulmus* and *Alnus* are found in frequencies typical for the *Ulmus*-*Alnus* sub-zone. The younger hiatus comprises the upper part of the *Pinus*-*Betula*-*Corylus*-*Alnus* PAZ (*Quercus*-*Ulmus* sub-zone). Immediately above the *Ulmus*-*Quercus* sub-zone *Ulmus*, *Tilia* and *Alnus* show frequencies characteristic of the *Pinus*-*Betula*-*Corylus*-*Alnus*-*Ulmus* PAZ. The *Pinus*-*Betula*-*Alnus*-*Carpinus*-*Fagus* PAZ is represented only by the sub-zone *Quercus*-*Picea*. The most extended and developed PAZ in this diagram is the *Pinus*-*Betula*-*Quercus*-*Corylus*-*Alnus* PAZ.

Pollen diagram WG B (Fig. 40)

In this pollen diagram no hiatuses are observable. The zone boundaries are very difficult to draw because of the rather strange pollen spectra, due to the serious overrepresentation of *Pinus*.

Because of these high values the zone boundaries between the *Ulmus* and *Ulmus*-*Alnus* sub-zones in the *Pinus*-*Betula*-*Corylus* PAZ and the upper limit of the *Pinus*-*Betula*-*Corylus* PAZ are hardly visible. On the contrary the *Pinus*-*Betula* PAZ, the *Pinus*-*Betula*-*Corylus*-*Alnus*-*Ulmus* PAZ and the *Pinus*-*Betula*-*Quercus*-*Corylus*-*Alnus* PAZ are all well developed in spite of the low frequencies for *Fraxinus* in the two last mentioned.

2. Description of the macrofossil diagrams

The aim of the macrofossil analysis is to establish possible fluctuations which occurred in the water level of the lake.

Changes in water level will be reflected in the macrofossil diagram by the differential spreading of fruits and seeds. The distribution of the shore vegetation depends on the water depth. A lowering of the water-level will mostly result in an outward spreading of the marginal macrophyte vegetation, while a rise in water-level will force the vegetation closer to the shore. It is possible to reconstruct these theoretical by means of an investigation of a line of macrofossil profiles (Digerfeldt 1972, 1979).

Some problems concerning the interpretation of and the different sources of error in macrofossil investigations are discussed more closely by Wasylikowa (1979).

The analysis also comprises a determination of the amount of coarse organic and minerogenic matter in the washed samples.

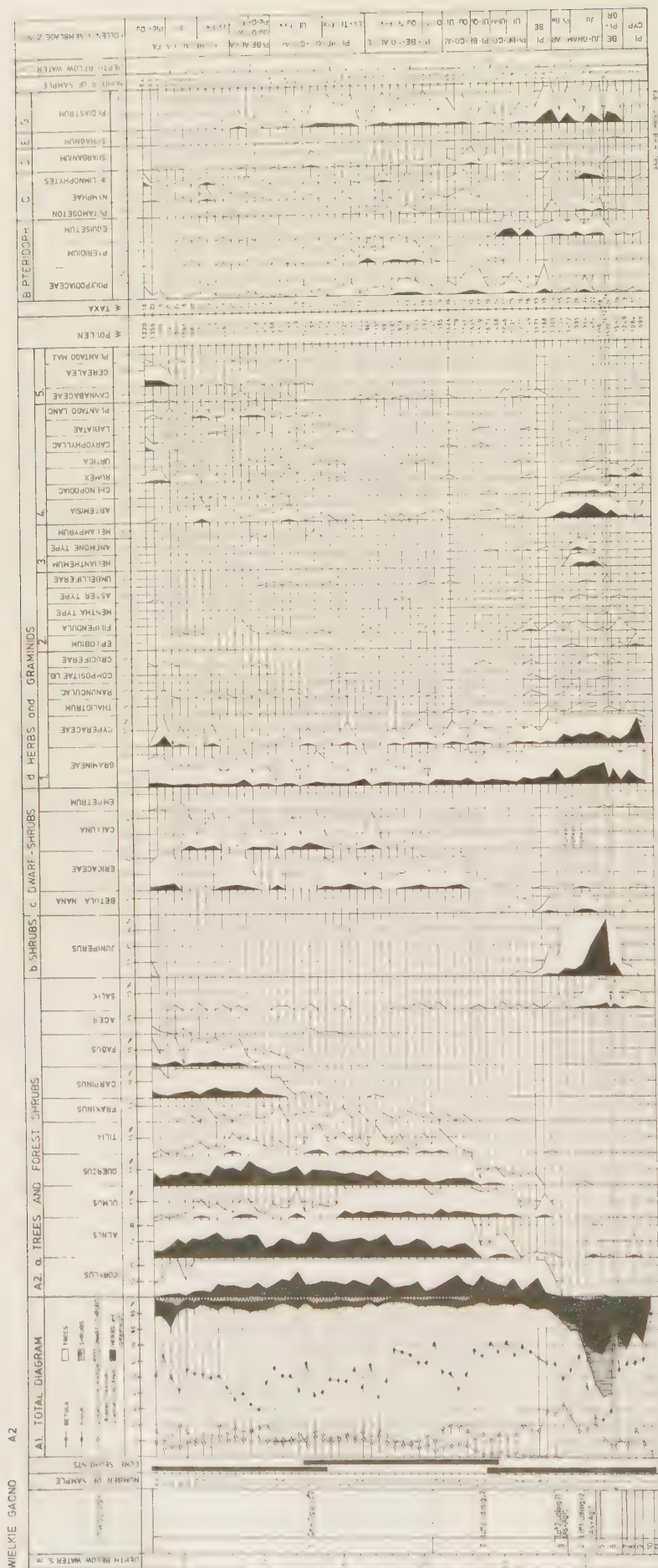
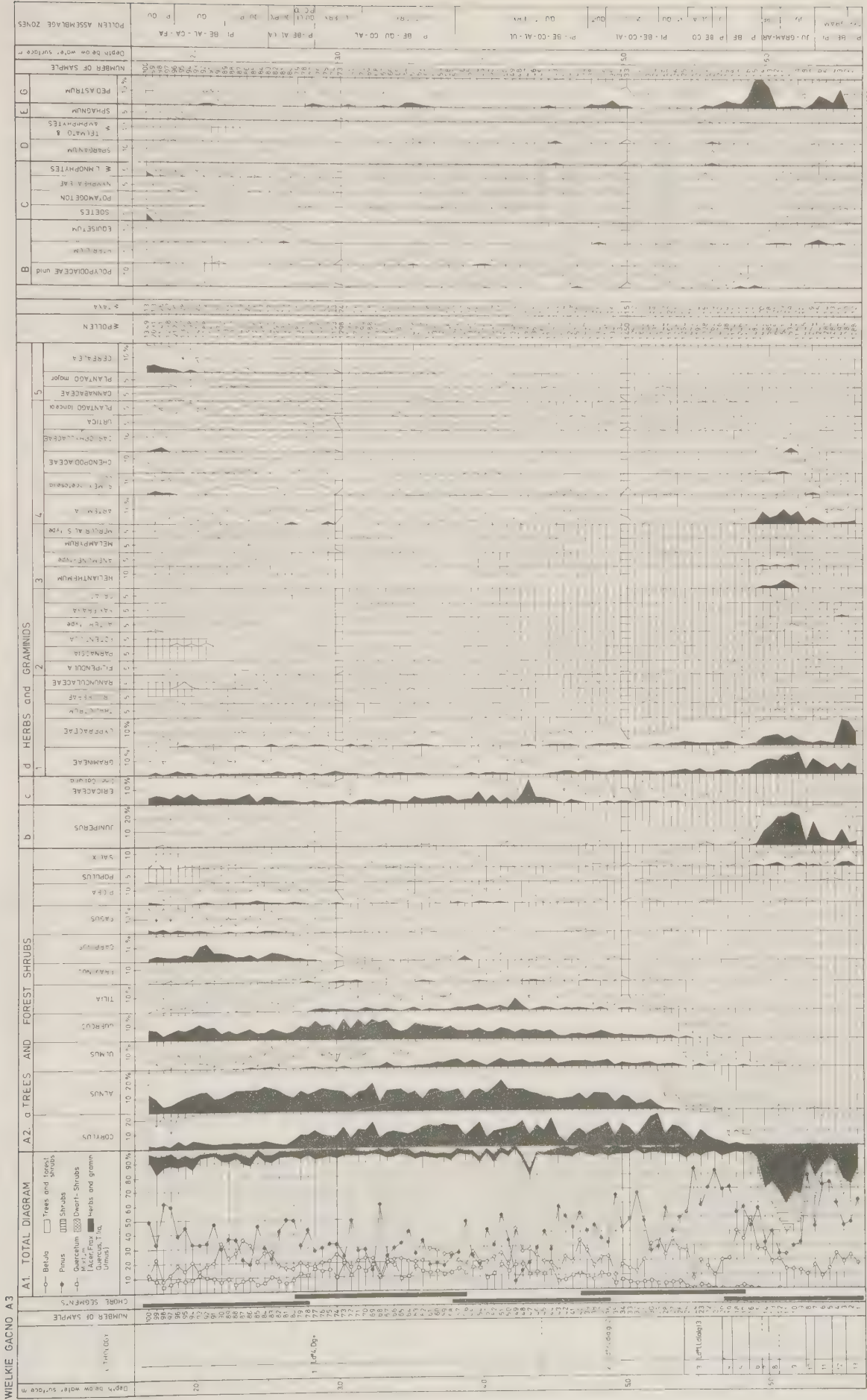


Figure 37. Relative pollen diagram

	WG A2. In the stratigraphy layers:
5 = (As+Ag)/3, (Ga+Gs)/1	6 = Ld ^{O2} , Ld(alg)/1, (As+Ag)/1, (Ga+Gs)+
7 = Ag ² , (Ga+Gs)/2	8 = Ld ^{O2} , Ld(alg)/1, (As+Ag)/1
9 = Ld ^{O+} , Ld(alg)/4	10 = Ld ^{O2} , Ld(alg)/1, (Ga+Gs)/1
11 = Ag ² , (Ga+Gs)/2	



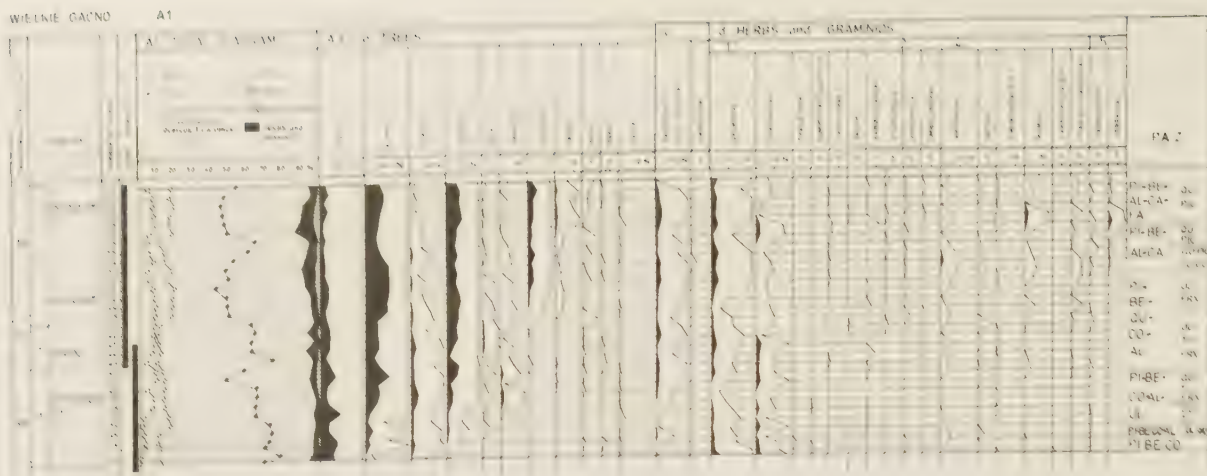


Figure 39. Relative pollen daigram WG A1 - the Holocene part. (The Late-Glacial part, see Fig. 27). The frequencies of the pollen groups B,C,D and G have been so low, that the diagram is excluding these species.

The principle behind the interpretation of the coarse organic and minerogenic material in the sediment is that sediment deposited in shallow water close to the shore will normally contain a larger amount of both coarse organic material originating from the marginal macrophyte vegetation, and reworked coarse minerogenic material. Changes in the amount of the coarse material may accordingly indicate displacement of the shore connected with water-level changes.

In lakes like Wielkie Gacno, which are characterized by a rather sparse and restricted marginal macrophyte vegetation, the determination of the coarse organic and minerogenic matter will, on the whole, give more reliable and detailed information about water-level changes than the seed and fruit analysis.

The description concerns only the Holocene part of the profiles. The Late-Glacial part will be described separately later.

Macrofossil diagram WG A3 (Fig. 41)

Four more or less distinct maxima of coarse organic matter, which may indicate periods of relatively shallow water, are found in the Holocene part of the profile.

The first strong maximum of coarse organic matter occurs at the Late-Glacial Holocene boundary and continues for the whole of the Pinus-Betula PAZ. The next increase is during the middle and later part of the Pinus-Betula-Corylus-Alnus-Ulmus PAZ, culminating slightly before the Pinus-Betula-Corylus-Alnus-Ulmus PAZ Pinus-Betula-Quercus-Corylus-Alnus PAZ boundary. During the later part of the latter PAZ the amount of coarse organic matter increases again, but rather temporarily. The youngest shallow-water period is registered during the later part of the Pinus-Betula-Alnus-Carpinus PAZ and during the early and middle part of the Pinus-Betula-Alnus-Carpinus-Fagus PAZ.

During all the increases of coarse organic matter, thought to indicate periods of shallow water, there is also increase in coarse minerogenic matter.

The Holocene sediment of this profile is rather poor in fruits and seeds and mostly without any particular indicative distribution. Only the second shallow-water period is independently confirmed by a distinct maximum of Potamogeton seeds. The highest frequencies are found around the culmination of this period, in the later part of the Pinus-Betula-Corylus-Alnus-Ulmus PAZ. Simultaneously fruits of Najas, occur. The unbroken curve for fruits of Nymphaea starts around the boundary between the Pinus-Betula-Quercus-Corylus-Alnus PAZ and the Pinus-Betula-Alnus-Carpinus PAZ.

Macrofossil diagram WG A2 (Fig. 42)

In the Holocene part of this profile four fairly distinct maxima of coarse organic matter indicating shallow-water periods are found. The first increase is registered during the Pinus-Betula PAZ. During the later part of the Pinus-Betula-Corylus-Alnus PAZ and the earlier part of the Pinus-Betula-Corylus-Alnus-Ulmus PAZ there is a second slight but distinct increase which culminates around the Quercus-Tilia and Quercus-Tilia-Fraxinus sub-zone boundary.

The third rise in coarse organic matter is found during the later part of the Pinus-Betula-Quercus-Corylus-Alnus PAZ. After a slight decrease it gradually rises again, attaining high values during the middle part of the Pinus-Betula-Alnus-Carpinus-Fagus PAZ, and this fourth shallow-water period seems to culminate during the Quercus sub-zone.

The occurrence of coarse minerogenic matter has a similar pattern to that of the coarse organic matter.

During the first shallow-water period a great number of seeds of Potamogeton and Carex are found. The sudden increase in unidentified Salicaceae bud-scales also occurs during this period. The unbroken curve for Betula fruits and fruit scales begins at the same point as the second rise in coarse organic matter. Slightly after the culmination

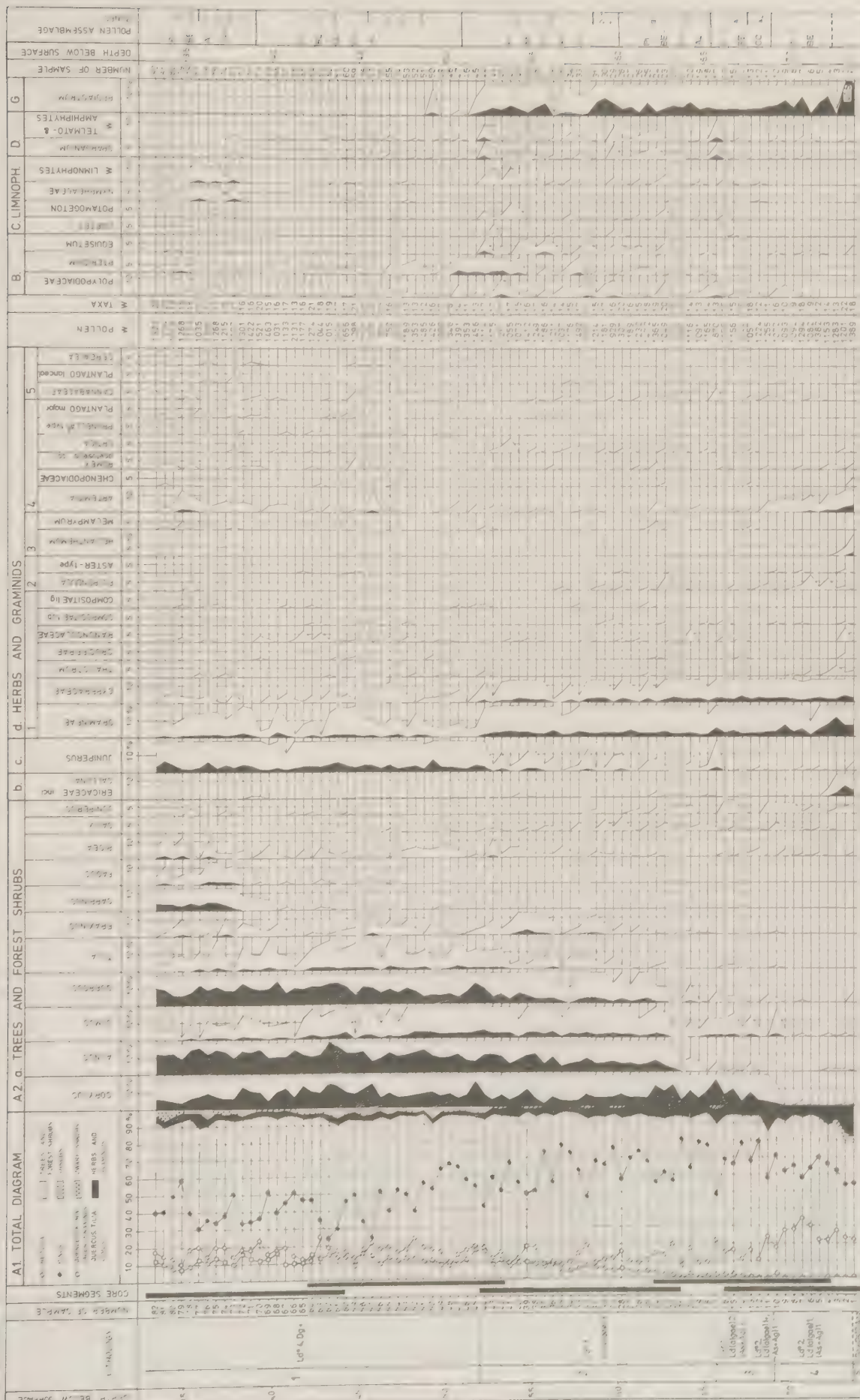
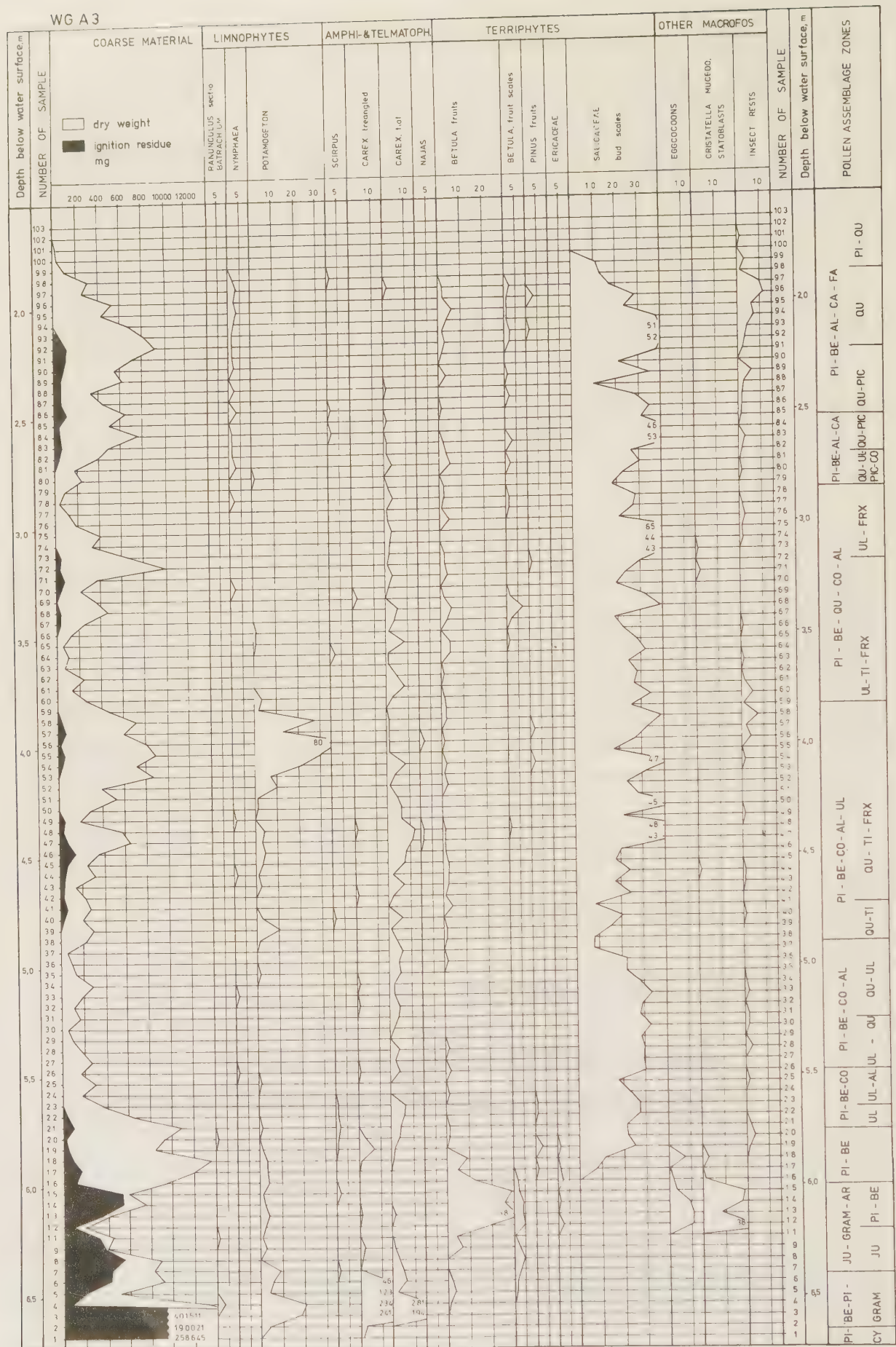
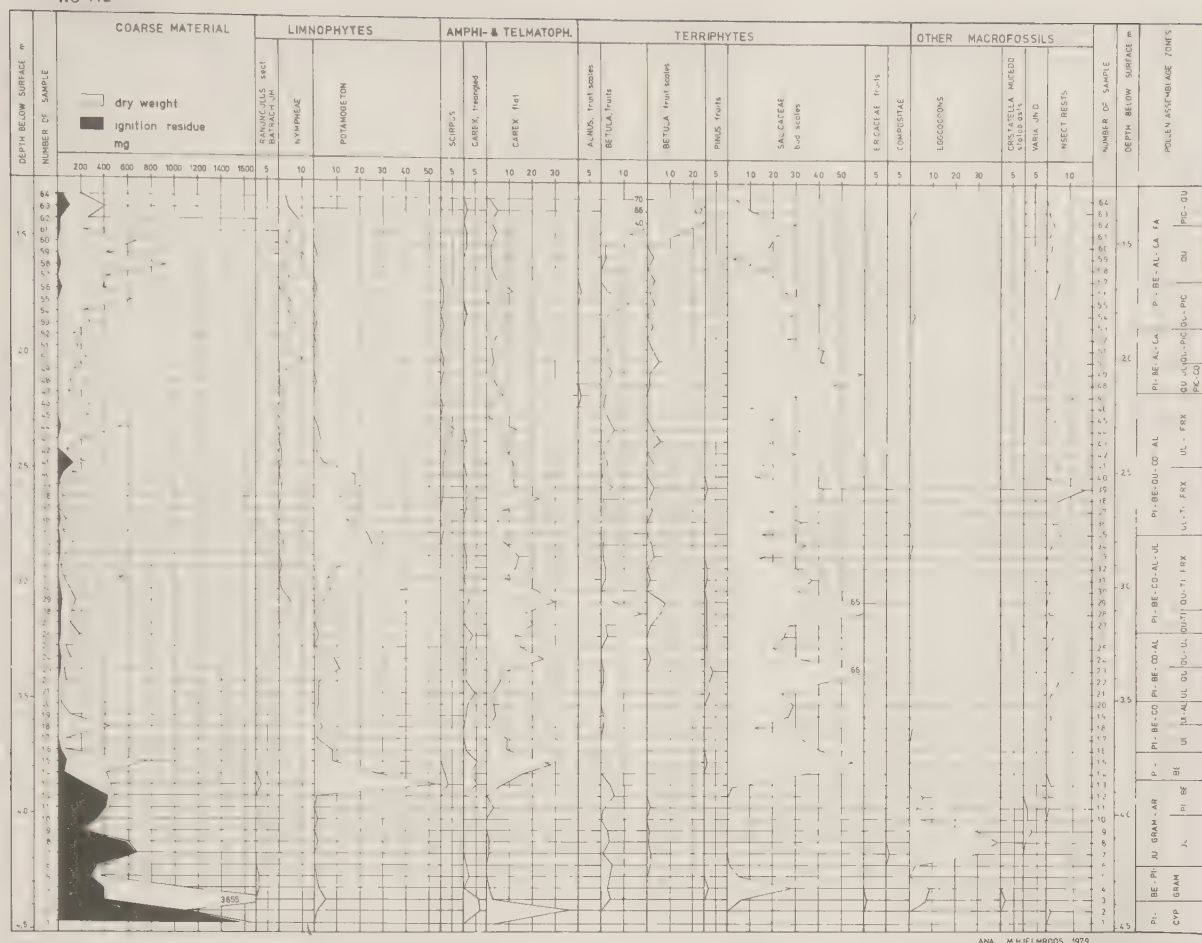


Figure 40. Relative pollen diagram WG B. (In the text WG B = WG B1)



ANAL. M. HJELMROOS 1979

Figure 41. Macrofossil diagram WG A3.



ANA. M. HJELMROOS 1979

Figure 42. Macrofossil diagram WG A2.

of this shallow-water period the curve for *Potamogeton* fruits attains high values. Simultaneous with the disappearance of *Potamogeton* the unbroken curve of *Nymphaea* begins, showing rather low but continuous frequencies during the upper part of this profile.

Slightly after the culmination of the last shallow-water period there is a strong increase in *Betula* fruits and fruit scales.

organic matter is found during the upper part of the *Pinus-Betula-Quercus-Corylus-Alnus* PAZ. After a temporary decrease the values for organic matter increase to the final maximum indicating a shallow-water period during the earlier part of the *Pinus-Betula-Alnus-Carpinus-Fagus* PAZ.

The coarse minerogenic matter shows only one distinct maximum during the Holocene in this profile. This rather strong maximum is found in the earliest part of the *Ulmus-Fraxinus-Tilia* sub-zone in the *Pinus-Betula-Quercus-Corylus-Alnus* PAZ.

Macrofossil diagram WG A1 (Fig. 43)

In the Holocene part of this profile two hiatuses are distinguishable. The older one comprises the *Pinus-Betula* PAZ and the earlier part of the *Pinus-Betula-Corylus-Alnus* PAZ, while the younger hiatus is expressed by the missing later part of the *Pinus-Betula-Corylus-Alnus* PAZ.

The coarse organic matter has three more or less distinct maxima during the Holocene. The first increase happens in the later part of the *Pinus-Betula-Corylus-Alnus-Ulmus* PAZ and then declines in the later part of the *Quercus-Tilia-Fraxinus* sub-zone. It should be emphasized that the frequencies of coarse organic matter throughout the whole of this profile are somewhat higher than in the other profiles. The second distinct rise in coarse

Perhaps because this profile is situated closest to the shore the frequencies of fruits and seeds are rather high. Two distinct maxima can be distinguished.

Slightly after the second hiatus, in the beginning of the *Pinus-Betula-Corylus-Alnus-Ulmus* PAZ a great number of fruits and seeds of *Carex* and *Potamogeton* are found reaching maxima simultaneous with the maximum of coarse organic matter. The fruits of *Nymphaea* and the fruits and fruit scales of *Betula* begin to occur at the same time though at rather low values. The frequencies of these increase gradually and attain maxima around the *Pinus-Betula-Alnus-Carpinus* PAZ and the *Pinus-Betula-Alnus-Carpinus-Fagus* PAZ boundary. During the last mentioned PAZ there are maxima of most of the other seeds and fruits, too (*Nymphaea*, *Scirpus*,

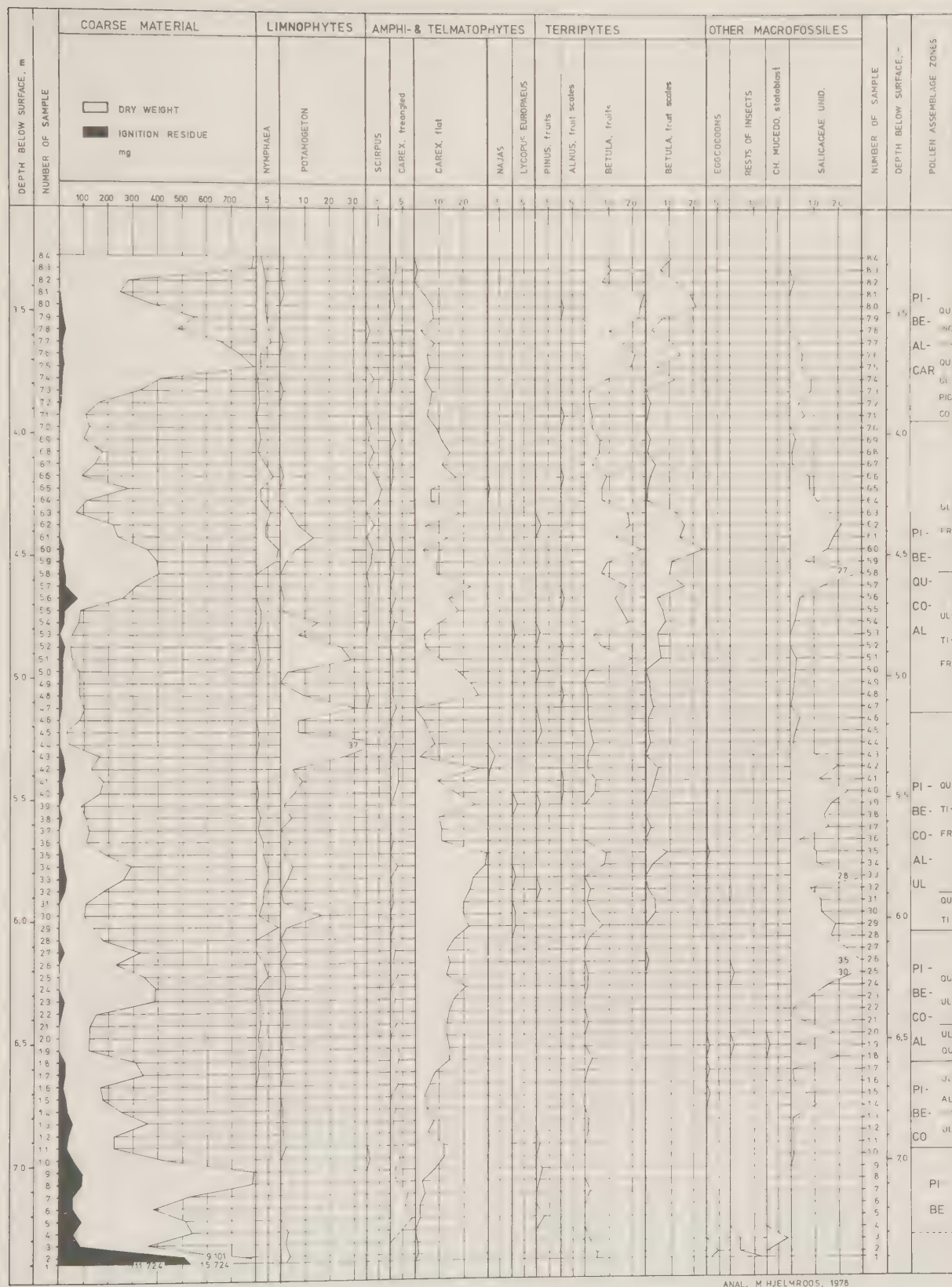


Figure 44. Macrofossil diagram WG B.

Tilia-Fraxinus and Ulmus-Fraxinus sub-zone boundary. The fifth rise occurs at the beginning of the Pinus-Betula-Alnus-Carpinus PAZ,

and continues to the uppermost sample of this profile.

The occurrence of seeds and fruits does

not have any particular pattern. A great number of *Potamogeton* fruits are found in the Pinus-Betula-Corylus-Alnus-Ulmus PAZ and in the Pinus-Betula-Quercus-Corylus-Alnus PAZ with a maximum around the PAZ boundary. Around the beginning of the supposed fourth shallow-water period registered in this profile the occurrence of *Betula* fruits and bud-scales increases distinctly. These curves then closely follow the curve for coarse organic matter during the upper part of the profile. The unbroken curve for *Nymphaea* fruits begins at the culmination of the fourth maximum of coarse organic matter.

3. Interpretation of water-level changes in Lake Wielkie Gacno

Because Lake Wielkie Gacno is situated on a sandy outwash plain without any inflow or outflow it is quite probable that changes in the water level of the lake have been caused by changes in climate.

As Digerfeldt (1975) has indicated changes in humidity lead to changes in water-level. Increased precipitation and/or falling temperature will cause a maximum rise in water-level while decreased precipitation and/or rising temperature will be followed by a maximum lowering in water-level. It is impossible, on the basis of water-level changes which have taken place, to say whether the change in humidity is caused by temperature or precipitation or both.

An interpretation of the possible water-level changes in Lake Wielkie Gacno on the basis of macrofossil investigations alone has proved difficult. However, analysing the content of the coarse matter, both the organic detritus and the minerogenic residue, has provided valuable support for the interpretation.

In the following the low-water periods have been treated separately starting with the oldest period, 1 and finishing with the youngest period, 5. Each lowering was succeeded by a renewed rise in the water-level, unless otherwise stated.

Low-water period 1.

The first low-water period during the Holocene, corresponding with the Pinus-Betula PAZ and the early part of the Pinus-Betula-Corylus PAZ, is recorded in profiles A2, A3 and B1 mainly as an increased amount of coarse organic and minerogenic matter in the sediment. At A1 there is a hiatus during the Pinus-Betula PAZ. This first low-water period corresponds to the transition Late-Glacial/Holocene and the greater part of the Pre-boreal chronozone.

The increased occurrence of minerogenic matter indicates that this period must have been caused by a real lowering of the lake water level. Since the shore line moved out-

wards the amount of reworked minerogenic matter increased in those profiles situated beyond the shore (A2, A3 and B1). The deposition limit during the culmination of this lower water-level was probably situated c. 2.8-3.0 metres below the present water level as illustrated in Fig. 45. The base of the Holocene sediments at profile A1 was situated above this limit, so with the lowering of the water-level the deposition of gyttja was impossible there. The rather poor representation of the Pinus-Betula-Corylus PAZ in diagrams A1, A2 and A3 indicates that at these points the bottom was situated quite close to the deposition limit.

The change in water-level is only vaguely recorded by the occurrence of seeds and fruits. In A2 there is a maximum of *Potamogeton* fruits in the earlier part of this period. The frequencies then decrease strongly indicating that the water-depth altered and soon became unsuitable for ephydate vegetation. The occurrence of some *Pinus* and *Betula* fruits can be explained by the decreased distance to the shore vegetation.

Low-water period 2.

The second lowering of the water-level during the Holocene is registered in two profiles, A1 and B1. At B1 the curve of coarse organic matter increases strongly in the middle part of the Pinus-Betula-Corylus-Alnus PAZ. The increasing amount of coarse minerogenic matter indicates that this was a real lowering of the water-level. At A1 the Quercus-Ulmus sub-zone is missing completely indicating that during the Late Boreal and the greater part of the Early Atlantic chronozone the deposition limit was c. 2.7-2.8 metres below the present water level.

This low-water period which is thought to have culminated around the middle part of the Early Atlantic chronozone is not registered in the macrofossil diagrams.

Low-water period 3.

This lowering is recognized more or less distinctly in all the profiles covering the major part of the Pinus-Betula-Corylus-Alnus-Ulmus PAZ which corresponds to the middle and later part of the Middle Atlantic chronozone. The period is considered to have culminated in the earlier part of the Late Atlantic chronozone. The period is considered to have culminated in the earlier part of the Late Atlantic chronozone.

The lowering of the water-level is most distinctly registered at A3, where a relatively strong rise in coarse minerogenic matter is seen.

At A2 and A1 the lowering is registered somewhat earlier and it is not as prolonged as at A3. At the inner A3 the lowering can be interpreted as being caused partly by natural infilling. In the sediments of this profile a large number of *Nymphaea* seeds have been found which perhaps originated from the near-by shore vegetation. The frequencies of *Nymphaea* decrease successively in the outer diagrams A2 and B1 and are found only sporadically in A3.

At the beginning of this period, in the middle part of the Middle Atlantic chronozone, there is a marked maximum of *Carex* at A2 and B1 followed by increasing values of

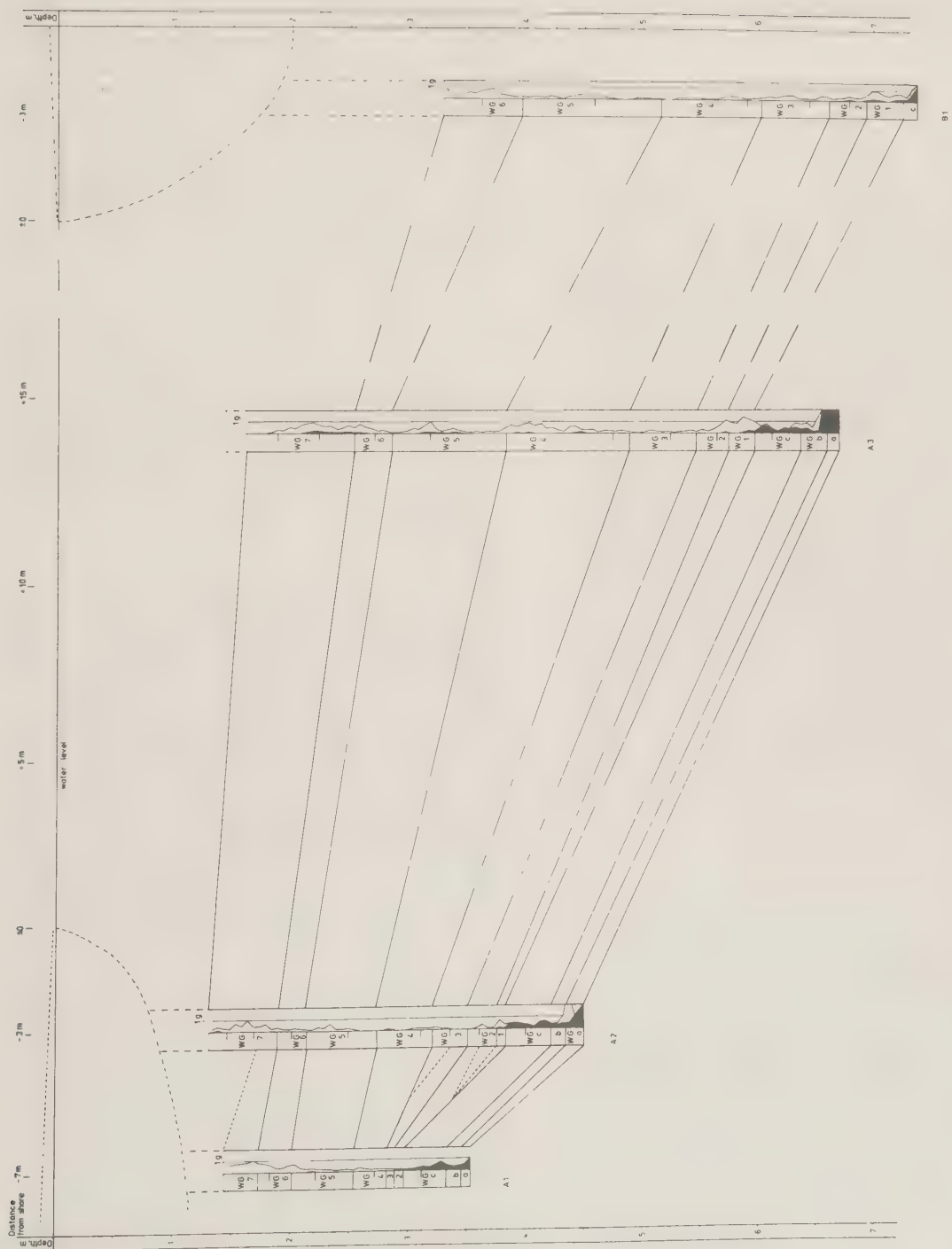


Figure 45. Correlation of the macrofossil profiles in Lake Wielkie Gacno. The map shows the location of the profile, pollen assemblage zones and the coarse matter (filled curve = ignition residue; unfilled curve = loss on ignition).

Potamogeton fruits in all profiles. This Potamogeton maximum is particularly marked at A3 where it coincides with high values of the curve of coarse organic matter. At A1 the high frequencies of Potamogeton span the low-water period, while at A2 and B1 the maximum is found slightly after the culmination of this lowering. During this period all profiles were close to the outward-spreading ephydate vegetation. The finds of Najas at A3 and B1 also provide that the shore was close to these sampling points.

Because the PAZ is well developed in all the profiles one can conclude that the base of the sampling points during this period was not as close to the deposition limit as during the previous low-water periods.

In the pollen diagrams, which are generally very poor in the pollen of aquatic plants, possibly because of the low number of pollen grains counted at each level, there is a slight rise in limnophyte pollen as well as in telmato- and amphiphyte pollen during this low water-level phase.

Low-water period 4.

The fourth lowering of the water-level in Lake Wielkie Gacno is registered distinctly in all diagrams by a rise in coarse organic and minerogenic matter in the middle part of the Pinus-Betula-Quercus-Corylus-Alnus PAZ which corresponds to the Early Sub-boreal chronozone. This increase culminates around the boundary between the Early and Middle Sub-boreal chronozones and is followed at A1 by a prolonged increase in coarse organic matter. At A1 values for the coarse minerogenic matter are rather low while the coarse organic matter shows high values throughout the whole period, probably indicating continued natural in filling in the immediate vicinity of the shore. This period is quite poor in fruits and seeds which mostly occur without any particular pattern. Nevertheless, Potamogeton, Carex, Scirpus and Nymphaea are all present probably originating from the ephydate vegetation or isolated stands which have spread outwards as a direct result of the lowered water-level. Nymphaea is often found close to the shore. At B1 there is a distinct increase in Betula fruit and bud scales simultaneously with the rise in coarse organic matter. This may be interpreted as an outward displacement of the shore although the increased spreading of the local shore vegetation could also be due to drift.

Low-water period 5.

The youngest lowering in Lake Wielkie Gacno during the Holocene is distinctly registered in all the profiles by a strong increase in both coarse organic and minerogenic matter. At A3 and A1 the increase begins in the middle part of the Pinus-Betula-Alnus-Carpinus PAZ and culminates around the middle part of the Pinus-Betula-Alnus-Carpinus-Fagus PAZ which corresponds to the Sub-boreal/ Sub-atlantic chronozone. In profiles A2 and B1 this period is more compressed, but the culmination occurs at about the same time as in A3 and A1. As a result of water-level lowering the deposition limit became displaced upwards which may be seen in the poor representation of the Pinus-Betula-Alnus-

Carpinus PAZ in all diagrams. The increase in coarse organic matter in the uppermost sediment at A1 and B1 is considered as an indicator of a gradual decrease in water-depth and the effect of natural in filling and plant succession at these points. This can also be seen in the increasing finds of seeds and fruits - Nymphaea, Menyanthes, Scirpus, Carex, Betula and Pinus - which belong to the shore and aquatic vegetation.

In the pollen diagrams A2 and B1 there is a distinct rise in Nymphaea pollen during this period which provides evidence of a position close to the shore. In the uppermost samples of A3 there are a large number of Isoetes-spores which represent the present vegetation in the littoral zone of the lake.

As discussed later on in connection with the palaeolimnology (Chapt. XII) it is thought that the water-level, as a whole, has been comparatively lower until the beginning of the Late Atlantic chronozone. During this earlier period three different lowerings of the water-level took place. From the investigated macrofossil diagrams it is evident that the deposition limit was situated notably lower at this time than afterwards.

This can be seen e.g. from the observed hiatuses in WG A1 and WG A2 profiles. The pollen assemblage zones WG 1, WG 2 and WG 3 are also more or less poorly developed and compressed.

4. Remarks on the water-level changes in Lake Wielkie Gacno - with a comparison to some other lakes in Poland and South Scandinavia

When reviewing the available Polish literature on water-level changes during the Holocene it is evident that a combined analysis of macrofossils and coarse material is only seldom used. The reconstruction of climatic change are usually made on the basis of palaeolimnological or lithostratigraphical investigations. The Polish work is poor in datings and consequently an absolute chronology is lacking. Authors have used the terms 'Preboreal', 'Boreal', 'Atlantic', 'Sub-boreal' and 'Sub-atlantic' time without any more detailed account of which of the many systems of biostratigraphic units have been used (for the systems of Nilsson, Fjörbas or Jessen, see Fig. 22). The incoherence of the studies has made a comparison between the various investigations difficult and for this reason they are only superficially treated here.

On the other hand, a more detailed comparison has been carried out between Lake Wielkie Gacno and some recently investigated lakes from southern Sweden. A schematic illustration of the most important studies from southern Sweden is shown in Fig. 46, in which the assumed lowerings in water-level for selected areas in Poland are also illustrated.

Nilsson (1935) presented a comprehensive pollen analytical investigation from numerous Scanian bogs and ancient lakes which also dealt with the problem of water-level changes

during the Holocene. He distinguished the lowerings in water-level on the basis of lowered deposition limits recorded, for example by hiatuses. For the younger Holocene, his interpretation of humidity changes was based on recurrence surfaces in raised bogs (RY in Fig. 46. RY = Rekurrens yta, Swedish).

In a later investigation, Nilsson (1967) presented a hypothetical water-level curve based on results from Ageröds mosse and Rönneholms mosse. In this, water-level changes during the early Holocene were treated in more detailed and a revision of the investigation from 1935 was made. The profile from Ageröds mosse is well dated (Nilsson 1974) by ^{14}C and thus directly comparable with the results from Lake Wielkie Gacno.

Nilsson (1964, 1967) described a major water-level lowering in BO 1, viz., in the Late Preboreal chronozone and a more minor one in BO 2, viz., in the Late Boreal chronozone. In the 1935 study water-level changes during AT 1 - AT 2 are not clearly established but in the later investigations Nilsson demonstrated a lowering which started around the 'AT 1/AT 2' boundary and culminating in AT 2, viz., in the Late Atlantic chronozone. This was followed by a gradual rise in water-level with some fluctuations which was demonstrated from Ageröds mosse.

Digerfeldt has presented six major works from southern Sweden, where water-level changes were established by means of macrofossil analysis of several profiles taken outwards from the shore: Lakes Vielängen and Farlängen (1965), the ancient lake at Torreberga (1971), Lake Trummen (1972), Lake Immeln (1974), Lake Våxjösjön (1975) and Lake Lyngsjön (1976). The chronology of each investigation is comparable to that of Lake Wielkie Gacno. In all the localities investigated by Digerfeldt a major lowering of water-level took place during the later part of PB and the earlier of BO 1, viz., in the Late Preboreal chronozone.

A short-term lowering is thought to have taken place in the ancient lake at Torreberga (Digerfeldt 1971) as early as the transition from the Late Glacial to Holocene time and a second major one in the later part of PB - earlier part of the BO 1.

This second lowering is especially well established in Lake Lyngsjön (Digerfeldt 1976) by the presence of a *Phragmites* peat-layer. In lake Våxjösjön (Digerfeldt 1975) a minor was observed at the AT 1/AT 2, zone boundary, viz., around the boundary between the Early and the Middle Atlantic chrozozones. Another major lowering in water-level took place in the later part of SB 1 and the earlier part of SB 2, viz., around the Early-Middle Sub-boreal chronozone. The duration of this lowering is of a different magnitude depending on the locality, but the maximum at each locality is, assumed to have occurred at the same time. this lowering is seen clearly in lakes Vielängen and Farlängen (Digerfeldt 1965).

The most recent lowering occurred some time in SA 1, viz., in the Middle Sub-atlantic chronozone, and is well established in lake Våxjösjön (Digerfeldt 1975).

In connection with the investigations of both Nilsson and Digerfeldt it should be stressed that only the major changes in water-level have been discussed. In addition to these there have been several minor fluctuations during the Holocene which can be related to the recurrence surfaces defined by Nilsson (1935) in Scania (Fig. 46).

In Lake Wielkie Gacno five major lowerings in water-level have been established for

the Holocene, indicating five periods of drier climate. The culmination of the earliest lowering is dated to around the Early Preboreal chronozone. It seems to agree well with the results from Southern Sweden. As in the ancient lake at Torreberga (Digerfeldt 1971) traces of a short-time lowering around the Younger Dryas/Preboreal chronozone boundary succeeded by a temporary rise in water-level before the major lowering in the Early Preboreal chronozone are also found here. This short-term change in the climate is dated to the earliest part of the Early Preboreal chronozone. This transitory cooler period in the beginning of the Holocene is also found in northern Central Europe and north-western Europe (e.g. Behre 1966, van Geel & Kolstrup 1978).

Many Polish authors have also placed the earliest lowering in water-level in the 'Preboreal' period and assumed that the culmination occurred during the early 'Boreal' period.

It is, however, clear that the climate during the Preboreal chronozone was dryer than that of the preceding period, and the lowering of the water-level at that time is regarded as being the greatest of all those established in Lake Wielkie Gacno.

The lowering in water-level registered at the Late Boreal/Early Atlantic chronozone boundary was fairly pronounced in Lake Wielkie Gacno. It is thought to correspond to the lowering in BO 2 found by Nilsson (1935, 1967).

The fall in water-level found in the Middle Atlantic chronozone which is thought to have culminated in the earlier part of the Late Atlantic chronozone is a slight one. It may be compared with the lowering indicated in lake Våxjösjön (Digerfeldt 1975). In Lake Wielkie Gacno this lowering indicates a temporary drier period and/or an increase in temperature which was soon succeeded by a rise in water-level.

In southern Sweden the youngest major lowering has been established by Digerfeldt (open cit.) as occurring in the Sub-boreal chronozone. This lowering is recorded distinctly in lakes Våxjösjön (Digerfeldt 1975) and Trummen (1972) by a hiatus and a clear lowering of the deposition limit. This fall in water-level is thought to have been caused by a distinct decrease in humidity.

The palaeolimnological evidence from NE Poland shows the beginning of a drier period during the transition 'Atlantic'/'Sub-boreal' periods. These results may be correlated with the fourth lowering of water-level found in Lake Wielkie Gacno. The culmination of this is assumed to have occurred around the Early/Middle Sub-boreal chronozone boundary. As a result of the fall in water-level the gyttja deposited during that time is seen to thin out, indicating that the lowering was probably of some magnitude.

The last fall in water-level during the Holocene in Lake Wielkie Gacno also seems to agree with the investigations from southern Sweden. It is evident from the curves of the Index of lake level and the Index of lake shape regularity presented by Mikulski (1978) that during the 'middle sub-atlantic' period in northern Poland a lowering of lake water-level took place. On the base of *Cladocera* investigations (Czeczuga 1975) it is predicted that in NE-Poland a short warm and moderately humid period occurred during the 'middle Sub-atlantic' period, called the Neo-boreal period (1970 - 1200 B.P. according to Czeczuga 1959).

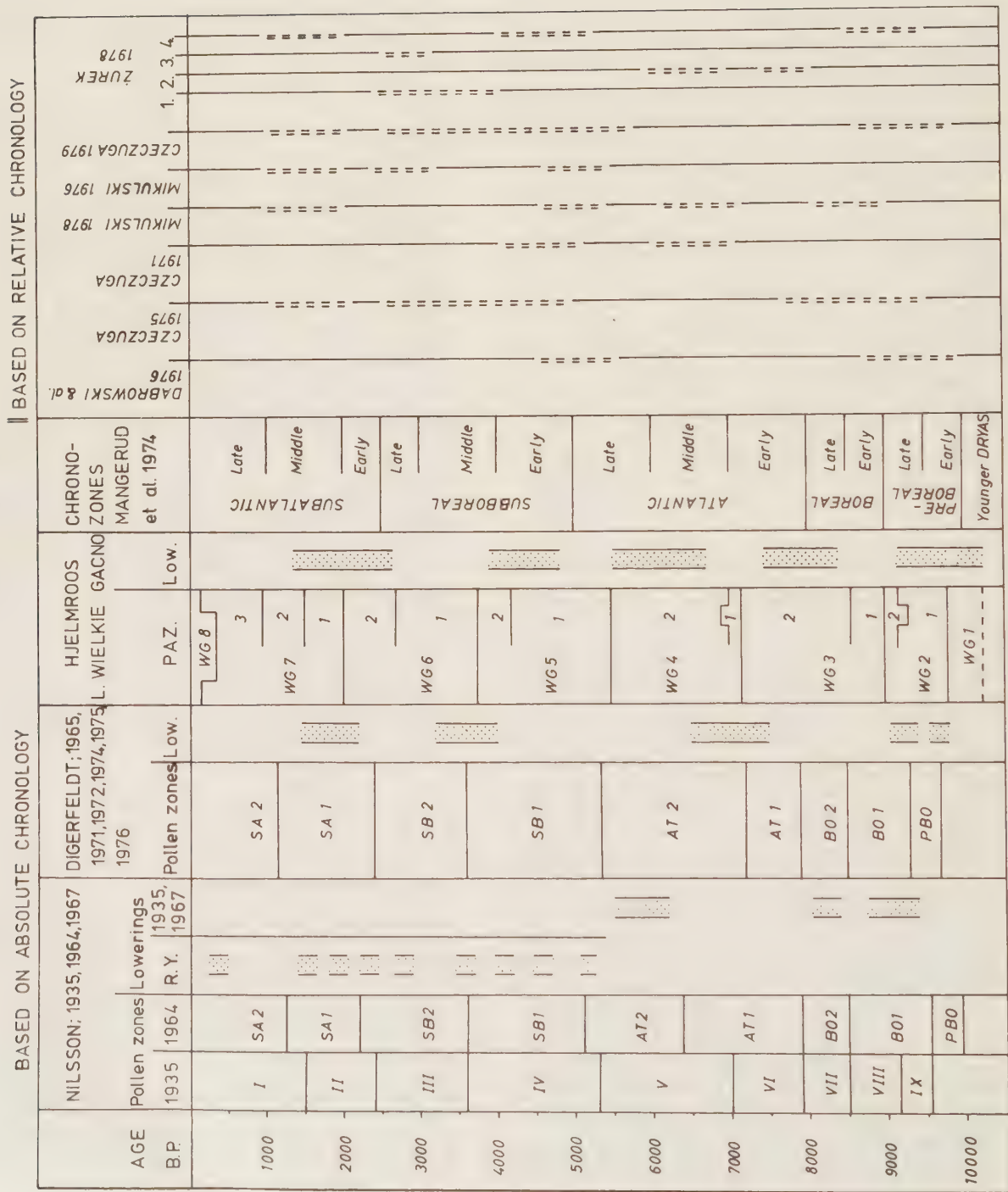


Figure 46. Comparison between the established Holocene water level changes in Lake Wlk. Gacno and the most important studies from Southern Sweden (based on the absolute chronology) as well some Polish studies based on the relative chronology.

The general picture of climatic changes during the Holocene in Lake Wielkie Gacno seems to follow the same pattern as in southern Sweden and also that for northern Poland as presented in previous investigations.

XII. PALAEOLIMNOLOGY

The interpretation of the limnological development of Lake Wielkie Gacno during the Holocene is based on sediment chemical and physical analyses and on diatom analysis.

For a closer study of the palaeolimnological principals see Frey (1969, 1974), Batterbee (1979 and the litt. cit. therein) and Bengtsson (1979 and the litt. cit. therein).

A cladocera analysis has been carried out by prof. J. Mikulski, Torun, but this will be published separately.

1. Diatomée analysis

Diatoms are very important in palaeolimnology due to the large number of species and their differing ecological requirements.

On the basis of community analyses information of the past water-pH, salinity and productivity of the lake basin can be provided (Frey 1972, Batterbee 1979). In this study the limnological lake development is interpreted by grouping the diatoms according to pH, salinity and life-form requirements. The grouping of the diatoms is made according to Chlcnoky (1968), Cleve-Euler (1951-1955), Fjordingstad (1954), Foged (1977, 1978, 1979, 1980), Hustedt (1937), Mölder & Tynni (1969-1973), Nygaard (1956) Patrick & Reimer (1966, 1975), Simonsen (1962), Tynni (1975, 1976, 1978). In controversial cases the majority opinion has mostly been followed.

pH grouping (Figs. 47-48)

A grouping of the diatoms according to their water pH requirements is one of the most useful interpretation methods. It is widely known that different diatom forms have their optimum occurrence within different pH limits. This is a reflection of either the pH value itself or of factors which are correlated to pH (e.g. Jørgensen 1948). In this investigation the diatoms are grouped according to the system proposed by Hustedt (1939):

- alkalibiontic forms: diatoms occurring at pH values above 7,
- alkaliphilous forms: diatoms occurring at pH c 7, however, the optimal distribution occurs at pH above 7,
- indifferent forms: diatoms occurring equally on both sides of pH 7,
- acidophilous forms: diatoms occurring at pH c 7, however, the optimal distribution occurs at pH below 7,
- acidobiontic forms: diatoms occurring at pH values below 7, the optimal distribution occurs at pH c 5.5 and below.

In the following classification the number of *Tabellaria* and *Fragilaria* individuals has been excluded. These diatoms are found in such great numbers that they would obscure the final results.

In the following calculations and illustrations the acidobiontic and acidophilous diatoms are counted together and illustrated by one

curve. The same is true for the alkalibiontic and alkaliphilous species.

With respect to the number of individuals, the alkalibiontic and alkaliphilous forms are distinctly dominant during the early lake development, up until the Middle/Late Atlantic chronozone boundary, when they form between 60 and 80 % of the total. Thereafter they decrease dramatically to around 15-20 %, and in the Early Sub-atlantic chronozone alkalibiontic and alkaliphilous forms almost disappear. In the latest part of the lake development there is a slight but distinct increase in the occurrence of those forms to c. 20 %.

The acidobiontic and acidophilous forms are present in very low frequencies during the Preboreal chronozone, but are more or less absent during the Boreal and earlier part of the Atlantic chronozone. During the Late Atlantic chronozone they gradually begin to occur at higher values and, in the Sub-boreal chronozone, the frequencies range between 10 and 20 %. Around the Sub-boreal/Sub-atlantic chronozone boundary the number of individuals of acidobiontic and acidophilous diatoms increases distinctly. During the Sub-atlantic chronozone there are fairly strong short-term variations, but at values of between 35 and 40 %.

The tendency for acidophilous and acidobiontic forms to increase upwards in the profile and for alkaliphilous and alkalibiontic forms to decrease is balanced by the occurrence of indifferent forms. These increase until the Sub-boreal chronozone where they reach a maximum of 75-80 %. In the most recent sediments these forms are gradually decreasing.

In Fig. 47 the most common and important diatoms are illustrated with respect to their pH requirements.

The acidobiontic and acidophilous diatoms are almost exclusively represented by different *Eunotia* forms among which *Eunotia faba* (EHR.) GRUN., *Eunotia faba fo. rhomboidea* FOGED and *Eunotia rhomboidea* are the most frequent species. They occur mainly from the Early Sub-boreal chronozone onwards. In the most recent sediments *Anomoeonis serians* var. *brachysira*, *Frustulia rhomboides* (EHR.) DE TONI and *F. rhomboides* var. *saxonica* (RABH.) DE TONI are found.

The indifferent diatoms *Achnanthes recurvata* (HUST.), *Cymbella gracilis* (RABH.) CL., *Eunotia lunaris* (EHR.) RABH., and *Navicula radiosa* KUTZ. have their maximum appearance in the Sub-boreal and Sub-atlantic chronozones while *Cymbella cuspidata* KUTZ., *Navicula pupula* var. *capitata* HUST., *Navicula wittrockii* (LAGERST.) A.CL. occur mainly in the early part of the lake development and are only rarely found from the Atlantic/Sub-boreal chronozone boundary onwards. It is thought that the earliest mentioned group of indifferent species have their optimum occurrence close to that of the acidobiontic and acidophilous species while the second mentioned form-group does not thrive under these conditions. The indifferent diatoms *Pinnularia gibba* EHR., *Pinnularia gibba* var. *linearis* HUST., and *Stauroneis phoenicenteron* EHR. are well represented throughout the whole of the lake development.

The majority of the alkalibiontic and alkaliphilous species have their maximum appearance during the early lake development

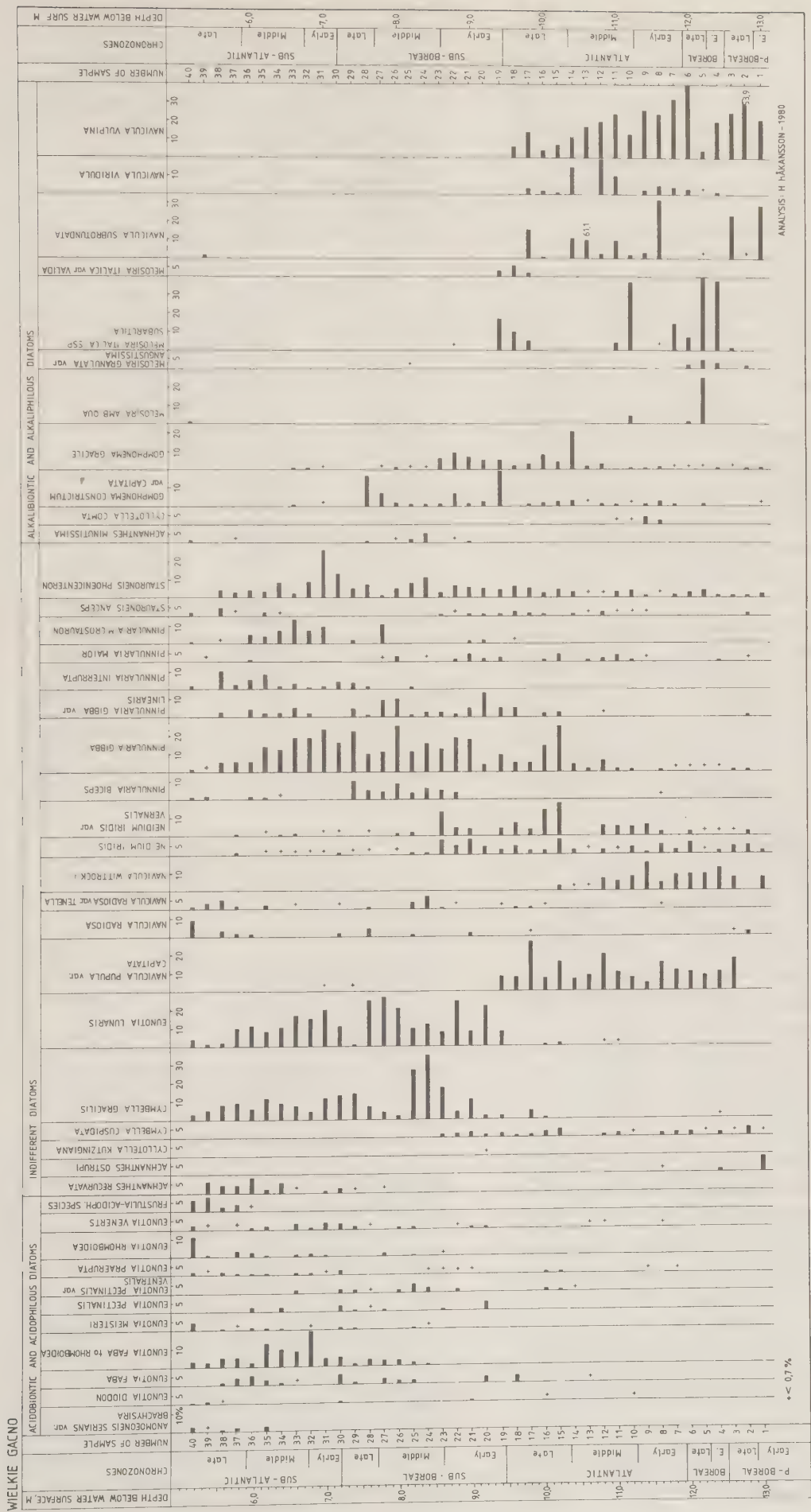


Figure 47. Most common and important diatoms in Lake Wielkie Gacno illustrated with respect to their pH requirements.

continuing until the Atlantic/Sub-boreal chronozone boundary (cf. *Melosira italica* ssp. *subarctica* O. MULLER, *Navicula subrotundata* SCHUMANN, *Navicula viridula* KUTZ., *Navicula vulpina* KUTZ.). *Achnanthes minutissima* KUTZ., however, has its maximum during the Middle Sub-boreal chronozone. *Gomphonema constrictum* var. *capitata* (EHR.) CL. and *G. gracile* EHR. occur more or less abundantly during the whole lake development. Their maximum occurrence is, however, during the Atlantic and Sub-boreal chronozones.

The development of the curves of the different diatom forms provides evidence of a gradual decline in the water pH towards the later part of the lake's development.

It should be emphasized that most of the *Fragilaria* forms present in the sediment are grouped as alkaliphilous in terms of their water-pH requirements and all these have their greatest occurrence during the earlier and middle period of lake development, culminating in the Middle Atlantic chronozone. The dominant *Fragilaria* forms are *Fragilaria construens* (EHR.) GRUN. and its variations *F. construens* var. *binodis* (EHR.) GRUN. and var. *venter* (EHR.) GRUN. From the beginning of the Sub-boreal chronozone onwards *Fragilaria* occurs only as single finds.

Tabellaria fenestrata (LYNGB.) KUTZ. and *T. flocculosa* (ROTH.) KUTZ. are regarded by most authors as acidophilous. Here, however, they are considered to be indifferent forms (cf. Knudson 1954, Florin 1957, Stoermer & Yuang 1970, Stoermer & Ladewski 1976). *T. fenestrata* has a strong maximum during the Late Atlantic and Early Sub-boreal chronozones.

The diatom composition of a lake is often characterized by grouping the forms into different pH intervals. Hustedt (1939) presented such a characterization where he grouped the diatoms according to the number of forms which occurred as at least 10 % of the total number of individuals. In the material from Lake Wielkie Gacno the total number of diatom-forms is quite stable throughout the lake development. However, only a few of these forms can be regarded as mass forms (die Massenformen), and so a pH characterization based on mass forms similar to that of Hustedt has proved unsuitable here. Nevertheless, it is evident that the water-pH was comparatively more alkaline up until the Atlantic/Sub-boreal chronozone boundary than during the Sub-boreal and Sub-atlantic chronozones.

Fjordingstad (1954) developed Hustedt's system by proposing a characterization based on the number of individuals. This has also been used, to some extent, in the Lake Wielkie Gacno material:

constantly acid waters: The acidobiontic and acidophilous forms constitute at least 70 % of the total number, the indifferents 0-30 %. The number of alkaliphilous species is always insignificant. It is impossible to distinguish between strongly acid and largely acid water because the acidobiontic species seem to have rather low frequencies even in strongly acid waters.

largely acid waters: Acidobiontic forms are almost absent, while acidophilous forms constitute c. 60 % (ranging between 42.5 and 70.7 %), and indifferent forms 20-35 % of the total number of diatoms. Alkaliphilous individuals are present.

largely neutral - alkaline waters: Acidophilous and indifferent forms together constitute c. 23-50 % while the alkaliphilous forms range between 44 and 67 %.

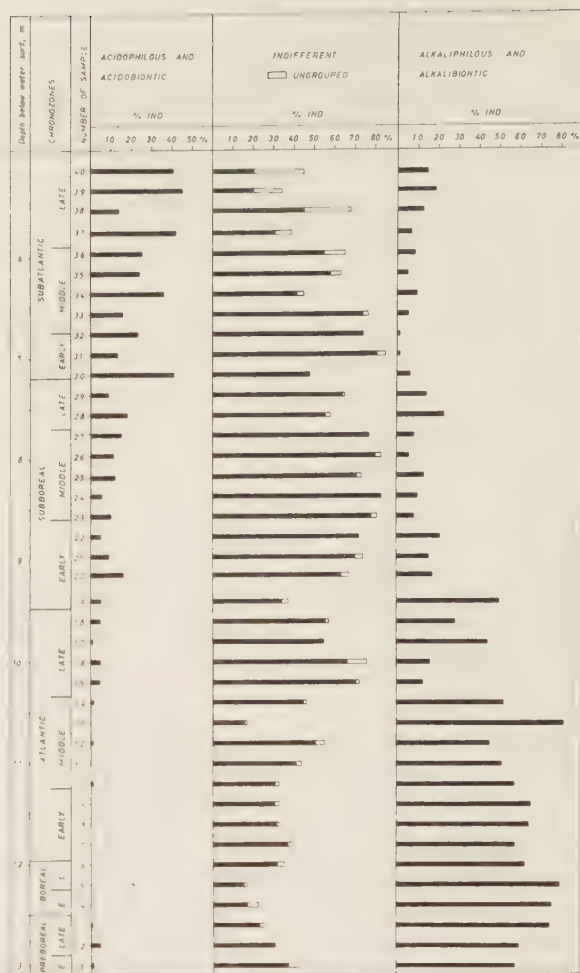


Figure 48. Diatom composition of Lake Wielkie Gacno according to the water pH requirements.

constantly alkaline waters: Alkalibiontic and alkaliphilous forms together constitute c. 90 % of the total number of diatoms. The alkalibiontic individuals seldom attain pre-dominance even if the waters are highly alkaline. Thus, on the basis of the diatoms alone, it is difficult to distinguish between water with a maximum pH 9.0 and those with a maximum pH 9.0.

In interpreting the results of the diatom investigation from the Lake Wielkie Gacno the characterization system of Fjordingstad has only been applied to the material from the late Sub-boreal chronozone onwards. The great dominance of acidophilous *Fragilaria* during the Pre-boreal, Boreal and earlier part of the Atlantic chronozones and that of the indifferent *Tabellaria* during the later part of the Atlantic and the earlier part of the Sub-boreal chronozones is thought to have a disturbing effect upon the interpretation. During the Late Sub-boreal and the earlier part of the Sub-atlantic chronozone the number of indifferent diatoms ranges between 55 and 70 %. Alkalibiontic and alkaliphilous species are present but acidobiontic and acidophilous species occur more frequently than before (20-30 %). This stage corresponds perhaps to a transition phase between the largely neutral-alkaline waters and the largely

acid waters.

In the uppermost sediments the acidobiontic and acidophilous species exceed 40 %. At this point the number of ungrouped forms ranges between 15 and 20 %. This is mainly due to the occurrence of *Navicula mediocris* KRASSKE which is regarded by Foged (1977) as a slightly acidic form (pH optimum c. 6.5), Cholnoky (1968), however, concluded that the optimum pH for this species would be around 8.4. The results from Lake Wielkie Gacno suggest that *N. mediocris* prefers water with pH 7 or more.

Nygaard (1956) presented a method of indicating the different water-pH forms by means of different indices calculated on the basis of the frequencies of alkaline and acid diatom-units. He did not, however, pay any attention to the indifferent forms. Meriläinen (1967) tested Nygaard's method and has also discussed the limitations of its use.

Because of the great number of indifferent individuals in the Lake Wielkie Gacno diatom-material this method is thought to be unreliable here. On the other hand, a test was made on the material from 14 different lakes and this do not supply a need of a reliable test of any investigation material.

Halobian grouping (Fig. 49)

Diatoms can be classified into different groups with respect to their salinity requirements. Kolbe (1927, 1932) presented a grouping system as follows:

Euhalobous forms with an optimum occurrence in waters with a salt content of 30-40 %.

Mesohalobous forms with an optimum occurrence in waters with a salt content of 5-20 %.

Oligohalobous forms with an optimum occurrence in waters with a salt content below 5 %.

The oligohalobous fresh-water diatoms were further divided into smaller groups. Hustedt (1953, 1956, 1957) has modified Kolbe's system to some extent, but agrees with Kolbe concerning the oligohalobous fresh-water diatoms:

- Halophilous forms = stimulated by a somewhat increased salt content, optimum in brackish water
- Indifferent forms = tolerate brackish water but with an optimum in freshwater
- Halophobous forms = cannot tolerate salt at all (limit of salt content 0.2 %).

As is apparent from Fig. 49 indifferent forms are dominant throughout the whole development of Lake Wielkie Gacno. Calculated per number of individuals (excl. *Tabellaria* and *Fragilaria*) they represent at least 80 % of the diatom flora. The indifferent forms reach their maximum during the Sub-boreal chronozone (90 %).

The halophobous forms are present during the earlier part of the lake development and up until the Middle Atlantic chronozone by c. 10 %. From then until the Early Sub-atlantic chronozone these forms remain mainly under 10 %, while in the uppermost sediments there is a slight increase (to 15-20 %).

The only halophilous form found in the Lake Wielkie Gacno sediment during the Holocene is *Nitschia frustulum* (KUTZ.)GRUN. which occurs sporadically in the most recent sediments.

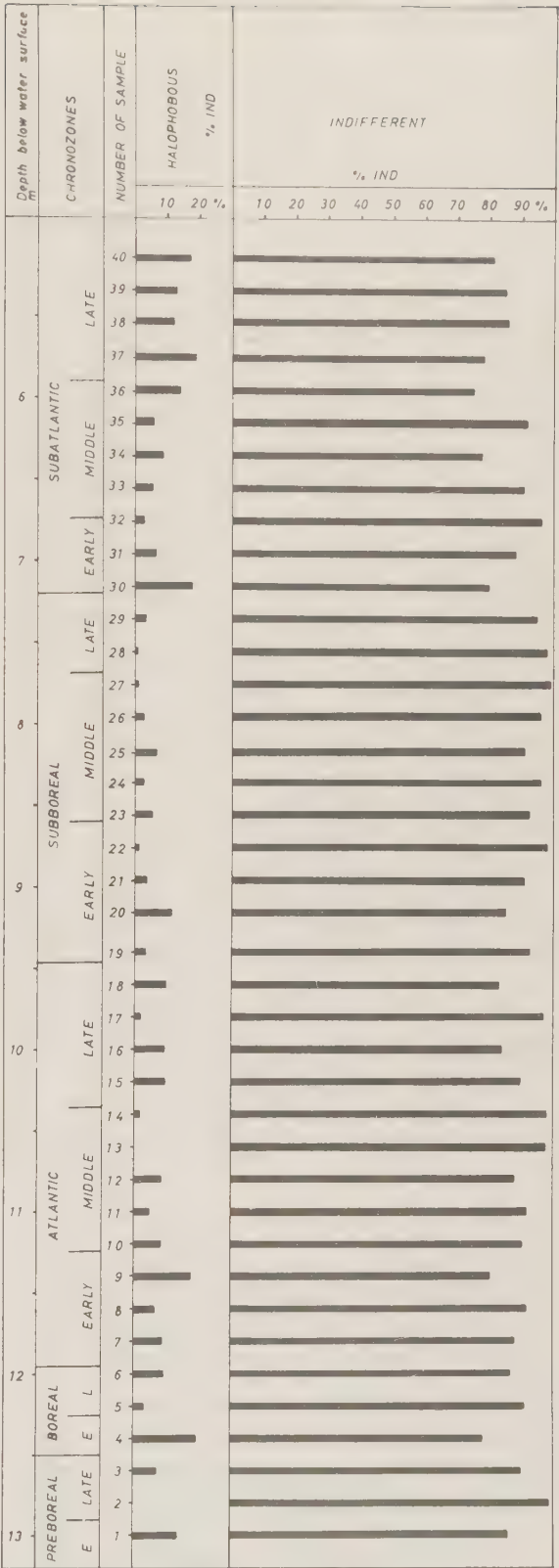


Figure 49. Diatom composition of Lake Wielkie Gacno according to their salinity requirements

The diatoms are divided according to their life-form into planktonic and periphytic groups. In Fig. 50, a life-form diagram, the total number of individuals (incl. *Fragilaria* and *Tabellaria*) forms the basis for the calculations.

In the Lake Wielkie Gacno sediment the planktonic forms comprise only a minute part of the total diatom flora up until the Middle/Late Atlantic zone boundary. In the Late Boreal and the earlier part of the Middle Atlantic chronozones the planktonic forms, however, show temporary rather high values. Around the Middle/Late Atlantic chronozone boundary the proportions change completely. Until the beginning of the Middle Atlantic chronozone the planktonic forms mainly comprises the genera *Melosira*. *Melosira granulata* var. *angustissima* O. MÜLLER is found during the Boreal chronozone and *M. italica* ssp. *subarctica* O. MÜLLER from the Late Pre-boreal until the Middle Atlantic chronozone at rather high values (35.0-40.0 %). Around the later part of the Late Atlantic chronozone *M. italica* var. *valida* GRUN. has its only occurrence during the Holocene. *Melosira ambigua* (GRUN) O. MÜLLER which appears trophically in fairly indifferent conditions is found only sporadically. From the Early Sub-boreal chronozone onwards *Melosira* occurs only sporadically.

The other planktonic forms to occur are *Cyclotella* and *Synedra* species. *Cyclotella comta* (EHR.) KÜTZ occurs in low frequencies during the Middle Atlantic chronozone and *C. kützingiana* THWAITES is found only once during the whole lake development. The sporadic finds of the planktonic *Synedra acus* var. *angustissima* GRUN. and *Synedra acus* var. *radians* (KÜTZ.) HUST. are concentrated in the same periods as the *Melosira*-occurrences.

Nevertheless, the most common planktonic form during the lake development is *Tabellaria*, which increases suddenly in the beginning of the Late Atlantic chronozone and reaches its Holocene maximum during the Early Sub-boreal chronozone (c. 60 %). In the later part of the Holocene *Tabellaria* is the only planktonic species ranging between 10 and 20 %.

During the early lake development the periphytic forms are strongly dominated by *Fragilaria* which has values of over 90 %. In the later part of the Atlantic chronozone *Fragilaria* decrease distinctly and thereafter occurs only sporadically. From the Late Atlantic chronozone up until the Late Sub-boreal chronozone periphytic forms comprise about 40-60 % of all diatoms. During the later part of the Holocene their frequencies increase to over 80 %.

Changes in the ratio between the planktonic and periphytic forms may provide information on changes in bathymetric and morphologic conditions during the development of the lake.

The strong dominance of periphytic forms, particularly *Fragilaria* may be evidence of changes in the lake water-level. As will be discussed in connection with the interpretation of the chemical sediment analysis it is improbable that the lake production has been so great that it can have had an effect upon the ratio.

On the contrary, the dominance of periphytic forms during the early Holocene is thought to be evidence of a generally shallower lake basin up until the Middle/Late Atlantic chronozone boundary.

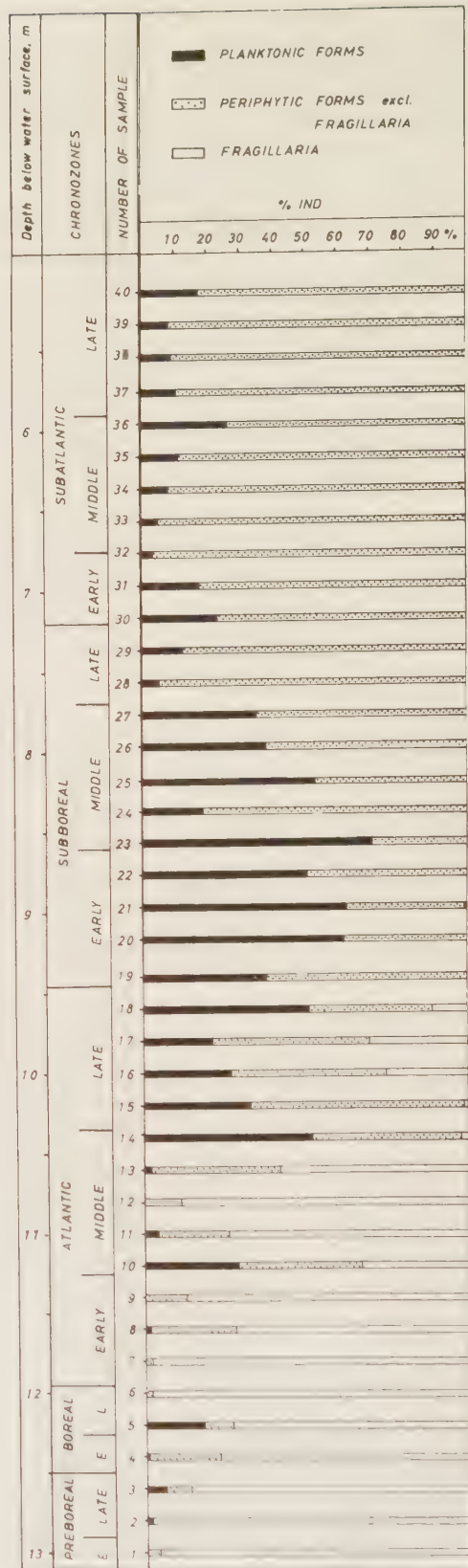


Figure 50. Diatom composition of Lake Wielkie Gacno according to their life-form.

During the later part of the Atlantic chronozone conditions changed suddenly. A distinct increase in planctonic forms, is observed due to the *Tabellaria* maximum in the Middle Holocene. That is thought to indicate generally higher water-levels and a deepening of the lake basin.

In the middle part of the Sub-boreal chronozone the frequencies of the periphytic forms begin successively to increase and comprise around 90 % of all diatoms from the Late Sub-boreal chronozone up until recent times.

The increase in periphytic forms has probably followed the morphometric changes in the lake basin in connection with the generally shallower Lake Wielki Gacno.

2. Sediment chemical analysis

The physical sediment analysis includes the determination of wet density, dry weight, water content, loss on ignition and ash weight. The sediment chemical analysis includes the determination of organic carbon, Kjeldahl-nitrogen, total phosphorus, iron, manganese, sodium, potassium, calcium and magnesium. The results of the analysis are presented in tables 8-11 and figs. 51-52.

Wet density and water content (Table 8)

The density of the sediment (weight of fresh sediment) is fairly even throughout the whole Holocene sequence. It does, however, decrease slightly during the Late Sub-atlantic chronozone. The density of the gyttja deposited during the Pre-boreal chronozone which contains more minerogenic material, is around 1.110 g/dm³.

During the Pre-boreal chronozone the water content is 50-65 % increasing strongly around the Pre-boreal/Boreal chronozone boundary to 90 %. In the algal gyttja, deposited up until the middle part of the Late Atlantic chronozone the water-content increases gradually to 95 %. During the Sub-boreal and Sub-atlantic chronozones, in the detritus gyttja, the water content attains maximal values of 98 %.

The changes in the wet density and the water content in the sediments of Lake Wielkie Gacno during the Holocene are presented in table 8 .

Organic material (=Loss on ignition), organic carbon, Kjeldahl-nitrogen and phosphorus (Fig. 51, Table 8-9)

The loss on ignition is used as an indicator of the amount of total organic matter in the sediment. the calculated annual accumulation of organic material is considered as an indicator of the productivity in a lake basin during its development.

Calculated per unit dry weight, organic material is present at a relatively constant level throughout. During the earlier part, until the beginning of the Sub-boreal chronozone, amounts are around 80 g/100 g or slightly under while, in the later part, loss on

Table 8.

Depth below water surface, cm	Number of sample	Rate of sediment accumulation mm/year	Wet density g/dm ³	Dry material g/dm ³	Water content	Loss on ignition	% of dry material
517	41	0.85	1004	34	96.8	22	68.5
537	40	0.85	1043	31	97.0	26	81.2
557	39	0.85	1006	31	96.9	28	88.4
577	38	0.85	1005	23	97.7	21	93.8
597	37	0.85	1004	21	97.9	20	94.9
617	36	0.85	1042	25	97.6	25	97.4
637	35	0.85	1058	32	96.9	32	99.4
657	34	0.85	1047	31	97.0	29	93.4
677	33	0.85	1074	40	96.2	36	89.9
697	32	0.85	1048	30	97.1	28	92.3
717	31	0.85	1070	40	96.1	35	88.2
737	30	0.85	1008	33	96.6	30	89.7
757	29	0.85	1044	38	96.4	31	83.2
777	28	0.85	1042	36	96.6	33	91.0
797	27	0.85	1020	33	96.7	29	88.9
815	26	0.85	1052	49	95.4	40	82.7
835	25	0.85	1051	34	96.8	31	93.4
855	24	0.85	1020	33	96.8	28	85.3
875	23	0.85	1076	28	97.4	27	96.1
895	22	0.85	1022	33	96.8	29	89.7
915	21	0.85	1011	44	95.6	39	86.9
935	20	0.85	1056	40	96.2	37	92.6
955	19	0.85	1040	50	95.2	40	79.7
975	18	0.85	1007	41	95.7	36	87.5
995	17	0.85	1051	43	95.8	37	85.1
1015	16	0.85	1022	51	94.9	42	80.8
1035	15	0.85	1002	66	93.4	39	59.9
1055	14	0.85	1001	62	93.7	35	55.7
1075	13	0.85	1014	49	95.2	39	80.6
1095	12	0.85	1004	42	95.7	36	84.3
1115	11	0.85	1053	69	93.1	38	55.9
1135	10	0.84	1005	51	94.9	41	80.4
1155	9	0.78	1062	53	95.0	44	83.0
1175	8	0.72	1025	58	94.3	44	76.2
1195	7	0.65	1040	60	94.2	46	77.9
1215	6	0.65	1021	63	93.8	51	80.7
1235	5	0.65	1002	64	93.5	53	81.0
1250	4	0.65	1030	69	93.3	54	79.2
1275	3	0.65	1041	71	93.0	58	80.3
1285	2	0.65	1054	77	92.6	59	77.0
1295	1	0.65	1106	108	94.6	67	62.3

ignition increases slightly reaching values of around 90 g/100 g dry weight. In the most recent samples the loss decreases to c. 65-70 g/100 g dry weight.

The highest loss on ignition per year is found in the sediments deposited during the Pre-boreal chronozone, with values in the lowermost sample of c. 45 g and thereafter of around 30 g/m². There is only a small variation in the loss during the greater part of the lake development, but in the Middle Sub-boreal chronozone the amount decreases slightly to attain a minimal accumulation of 15-20 g/m² around the Middle/Late Sub-atlantic chronozone boundary. In the uppermost samples the loss on ignition is around 20 g/m² per year.

Organic carbon and organic nitrogen are both bound in the organic material. The nitrogen is determined as Kjeldahl-nitrogen which comprises both organic nitrogen and ammonium nitrogen. The calculated per dry weight organic carbon and Kjeldahl-nitrogen both show the same changes as the total organic matter.

The lowest values are found in the Early

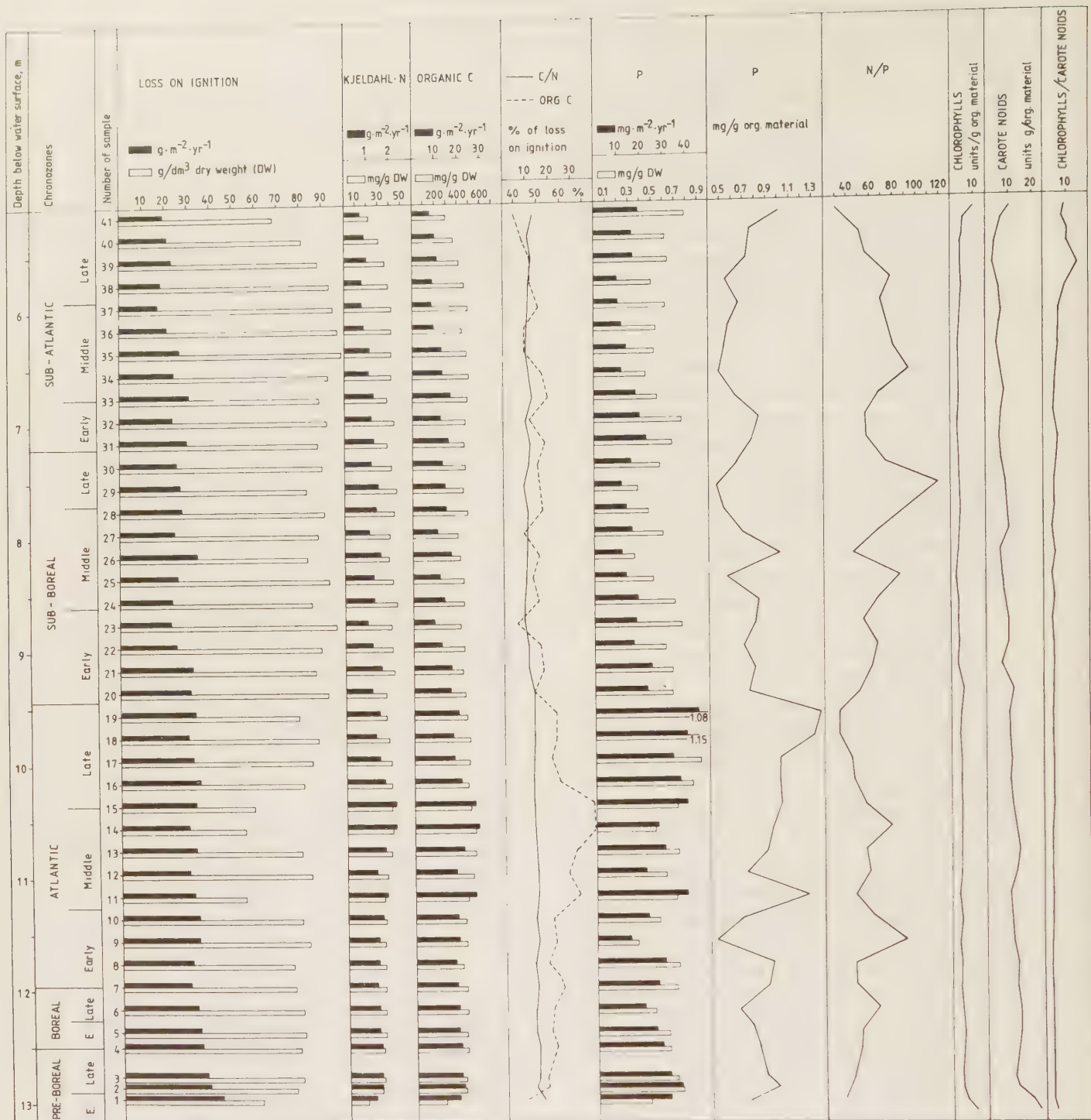


Figure 51. Sediment chemical analysis, Lake Wielkie Gacno, calculated per unit dry weight and per unit annual deposited sediment ($\text{g} / \text{mg} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$).

Pre-boreal (13 $\text{g} / 100 \text{ g}$ for organic - C and 8 $\text{g} / 100 \text{ g}$ for Kjeldahl-n), after which, amounts increase slightly to maximal Holocene around the Middle/Late Atlantic zone boundary (around 25 $\text{g} / 100 \text{ g}$ DW and 20 $\text{g} / 100 \text{ g}$ DW respectively). In the most recent sediments values decrease somewhat.

When calculated in terms of annual accumulation the changes in organic carbon and Kjeldahl-nitrogen mainly follow the curve for annual organic accumulation. During the early Holocene amounts remain fairly constant at c. 20 g / m^2 and 1.5 g / m^2 respectively. Both components reach their maximal

annual accumulation around the boundary between the Middle and Late Atlantic chrono- zones (28 g/m² and 22 g/m² respectively). From the Atlantic/Sub-boreal chronozone bound- ary onwards the amounts decrease slightly to reach their lowest values in the later part of the Sub-atlantic chronozone (7-10 g/m² for organic C and 0.7-1.0 g/m² for Kjeldahl nitrogen). However, both organic- C and Kjeldahl-N have somewhat higher accumu- lation rates around the Sub-boreal/Sub-at- lantic chronozone boundary before the above mentioned final slight decrease.

In the early part of the Holocene organic carbon is fairly constant at around 55 %, of the loss on ignition (with the exception of the lowermost sample where ther organic carbon/loss on ignition ratio is c. 40 %). During the Middle and Late Atlantic chrono- zone the proportions of organic C increase distinctly to over 65 %. In the latest part of the Atlantic chronozone the ratio diminishes successively and then ranges between 45 and 50 % during the greatest part of the later lake development. In the uppermost samples organic carbon represents c. 40 % of the loss on ignition.

The generally higher ratio between organic carbon and loss on ignition during the Middle and Late Atlantic chronozone is thought to depend on changes in the water-level of the lake. As discussed in Chapt. XI there is evidence for a low-water period in Lake Wielkie Gacno at that time. The rise in coarse organic material noticed in the macrofossil profiles during WG 4:2 and giving evidence for the third low-water period may have effected the rise in organic carbon in the main profile. It may also be a question of a different kind of carbonate, which entered the lake and caused a temporary maximum even in the main profile.

The C/N ratio is most often used to distin- guish between variations in the character of the sediment and changes in the humic character of the lake. Hansen (1959) has demonstrated that the higher C/N ratio will indicate a higher supply of allochthonous humus material, poor in nitrogen, from the soils surrounding the lake. According to Hansen, the boundary between gyttja and dy lies at the C/N ratio 10, thus sediments with a ratio lower than 10 should be classi- fied as gyttja and those with the C/N ratio higher than 10 as dy.

In Lake Wielkie Gacno the C/N quotient is decreases slightly upwards without any greater changes. In the algal gyttja, up to the beginning of the Sub-boreal chronozone, the ratio is somewhat higher than in the uppermost detritus gyttja (c. 13 and 10-11 respectively).

The variations in C/N quotient in Lake Wielkie Gacno are most probably dependant on changes in the composition of the algal and detritus gyttja.

Phosphorus and nitrogen are considered to regulate and determine the organic pro- duction. In Lake Wielkie Gacno the amount of P is relatively high throughout the whole lake development and it is thought that the supply of nitrogen may have been the limiting factor in the productivity of the lake.

The amount of phosphorus, calculated per dry weight, fluctuates strongly without any clear tendency. During the early part of the lake development, until the Middle Atlantic chronozone, phosphorus ranges be- tween 35 and 75 mg/g dry weight, and attains its maximum values (c. 95 - 115 mg/g DW) during the Late Atlantic chronozone. After that the amounts of P decrease distinctly and fluctuate from 35 to c. 70 mg/g dry

Table 9.

Depth below water surface, cm	Number of sample	Kjeldahl-N mg/g DW	Organic C mg/g DW	P mg/g DW
517	41	24.5	301	0.789
537	40	31.9	374	0.620
557	39	36.5	412	0.641
577	38	39.6	464	0.507
597	37	42.8	490	0.613
617	36	41.7	443	0.549
637	35	42.6	485	0.528
657	34	42.3	499	0.451
677	33	37.5	494	0.549
697	32	44.0	471	0.768
717	31	38.9	459	0.676
737	30	41.7	477	0.578
757	29	45.9	456	0.380
777	28	44.5	490	0.472
797	27	40.6	412	0.606
815	26	39.2	423	0.852
835	25	43.9	455	0.514
855	24	45.9	453	0.697
875	23	41.8	423	0.768
895	22	41.9	450	0.627
915	21	42.9	450	0.683
935	20	36.1	474	0.683
955	19	35.6	468	1.080
975	18	37.8	500	1.150
995	17	39.6	492	0.916
1015	16	39.1	483	0.859
1035	15	39.6	482	0.711
1055	14	41.0	501	0.521
1075	13	40.0	543	0.718
1095	12	36.2	544	0.613
1115	11	33.3	521	0.697
1135	10	34.6	478	0.556
1155	9	33.5	455	0.373
1175	8	34.3	473	0.719
1195	7	33.6	433	0.704
1215	6	34.1	472	0.514
1235	5	33.2	461	0.634
1250	4	32.8	462	0.641
1275	3	31.7	460	0.705
1285	2	30.9	432	0.754
1295	1	17.3	270	0.458

weight. From the Middle Sub-atlantic crono- zone until the most recent sediments phos- phorus is increasing, ultimately reaching a value of 80 mg/g dry weight.

The annual accumulation of phosphorus varies irregularly and differs rather distinct- ly from the general pattern of the annual accumulation of organic material. From the Pre-boreal chronozone until the beginning of the Atlantic chronozone P decreases slightly (from 35 mg/m² to 25 mg/m²) and then starts to rise. Around the Atlantic/Sub-boreal chrono- zone boundary the annual accumulation of P reaches its Holocene maximum of 40-45 mg/m². In the upper part of the Holocene amounts range mainly between 10 and 20 mg/m², and minimal values are found in the Middle part of the Sub-atlantic chrono- zone. In the most recent sediments there is a slight increase.

The significance of the ground-water in connection with the supply of phosphorus and other nutrients into lakes is almost un- known. Many authors suggest, however, that ground-water is an important factor in the flow of material from sediments outside the lake basin into the lake (Enell 1980 and the litt cit. therein).

Lake Wielkie Gacno is lacking in both inflow and outflow. The soils in the surroundings are poor sandy ones with a thin humus layer. It is thought that the catchment area of the lake is also fairly small (because of the unavailability maps it is impossible to determine the size exactly). Thus, the supply of nutrients at the surface waer of Lake Wielkie Gacno is thought to have been rather limited, and so the relative high, strongly fluctuating amounts of phosphorus may be correlated with probable fluctuations in the ground-water flow.

During the later part of the Atlantic chronozone increased humidity led to a general rise in ground-water level. The distinct maximum of phosphorus during that time is thought to reflect the increased inflow of ground-water.

The successive increase in the amounts of P during the Sub-atlantic chronozone can perhaps also be explained by a greater inflow of ground-water in connection with the still increased humidity.

When calculated per unit of organic material phosphorus also seems to vary strongly. However, P has generally higher values during the earlier part of lake development (0.6-0.9 mg/g) attaining a maximum in the later part of the Atlantic chronozone (over 1.3 mg/g organic material). Thereafter the curve falls, but has a distinct successive increase of 0.6 mg in the late Sub-atlantic chronozone. In the most recent sediments organic material comprises c. 1.1 mg phosphorus/g.

The fluctuations in the curve seem to follow closely and depends on the fluctuations of phosphorus calculated per dry weight.

The N/P ratio is usually used as an indicator of the nutrient status of lakes. During the early part of the lake development, up until the Atlantic/Sub-boreal chronozone boundary the ratio is relatively low with the minimum value during the Late Atlantic chronozone. From the Early Sub-boreal chronozone onwards to the middle part of the Sub-atlantic chronozone the N/P ratio increases distinctly but fluctuates strongly. In the upper part of the lake development the ratio decreases fairly obviously.

This ratio also seems to depend mostly on the amount of phosphorus calculated per dry weight. The lowest ratio is found during the Late Atlantic chronozone when the supply of P was very high and the nutrient status is thought to have been highest. The gradually decreasing N/P ratio during the later part of the Sub-atlantic chronozone may be partly connected with the decreasing amounts of Kjeldahl nitrogen in the uppermost sediments and partly with the increasing values of phosphorus, which probably depend on the increased humidity and on the greater ground-water inflow.

Sedimentary plant pigments (Fig. 51, Table 10)

The pigment analyses comprises the determination of the most dominant pigment groups in the sediment: chlorophylls and carotenoids.

In Lake Wielkie Gacno, variations in the amount of fossil pigments are fairly slight. There is, however, a clear maximum during the Early Pre-boreal chronozone. The values then decrease but still remain relatively high until the beginning of the Late Sub-boreal chronozone. The amount of fossil pig-

Table 10.

Depth below the water surface, cm	Number of sample	Chlorophyll units/g DW	Carotenoid units/g DW
517.5	43	9.3	11.0
527.5	42	5.4	6.9
537.5	41	5.1	5.3
547.5	40	3.8	4.0
567.5	39	4.4	3.0
587.5	38	4.9	5.3
607.5	37	4.1	6.4
637.5	36	3.0	4.5
657.5	35	3.3	6.1
677.5	34	3.6	7.7
697.5	33	2.9	6.4
717.5	32	3.1	5.4
737.5	31	3.4	6.6
757.5	30	3.5	8.4
777.5	29	4.0	8.9
797.5	28	3.8	10.0
817.5	27	2.7	5.9
837.5	26	2.3	6.8
857.5	25	3.2	8.1
877.5	24	3.3	9.5
897.5	23	3.6	9.0
917.5	22	2.9	6.5
937.5	21	4.7	11.6
957.5	20	4.1	10.1
977.5	19	3.7	10.4
997.5	18	4.4	11.1
1017.5	17	4.2	10.4
1037.5	16	4.5	11.5
1057.5	15	4.0	12.9
1077.5	14	4.2	13.8
1097.5	13	4.3	13.3
1117.5	12	3.4	10.1
1137.5	11	3.9	11.2
1157.5	10	2.9	10.9
1177.5	9	4.1	13.2
1197.5	8	3.9	12.9
1217.5	7	4.3	13.5
1237.5	6	5.1	14.3
1257.5	5	4.4	12.8
2377.5	4	4.1	12.0
2387.5	3	4.3	13.3
1297.5	2	6.2	18.8
1307.5	1	10.3	22.3

ments is low during the later part of the lake development with a slight but distinct increase in the most recent sediments. These somewhat higher values are most probably connected to the continuing successive decomposition of pigments recently entering the lake.

The chlorophyll/carotenoid ratio during the early part of the natural lake development is around 0.3-0.4. During the Middle Atlantic chronozone the ratio rises successively to 0.5. It reaches a maximum of 1.4 at the beginning of the Late Sub-atlantic chronozone and then decreases in the uppermost samples. The slightly higher ratio during the later part of the lake development is mainly caused by decreasing carotenoid concentration and increasing chlorophyll concentration.

Fossil plant pigments, especially the carotenoids and chlorophylls of terrestrial vegetation decompose mostly in soils and, therefore, the amount of these pigments in the allochthonous organic material entering

a lake from its drainage basin is usually fairly low (Gorham & Sanger 1975). The changes in pigment degradation and in the relationship between chlorophylls and carotenoids is often used in interpreting variations in the balance between allochthonous and autochthonous organic productivity (e.g. Gorham & Sanger 1975).

The higher values for sedimentary plant pigments during the Pre-boreal, Boreal and Atlantic chronozones in the Lake Wielkie Gacno sediments may be associated with the occurrence of algae, primarily green algae, in the sediment. The fall in the amount of pigments measured at the beginning of the Sub-boreal chronozone may indicate a decrease in lake productivity and a change in the sediment quality. However, it has been proved that even in poor oligotrophic lakes with oxygenated hypolimnions, a certain amount of organic material is derived from the surroundings of the lake. Terrestrial material is rich in derived chlorophyll whereas lake organisms produce a higher proportion of carotenoids (Gorham et al. 1974).

Nevertheless, as a whole, changes in the sedimentary plant pigments have been very low during the lake development without any greater variations.

Remarks on the productivity of Lake Wielkie Gacno during the Holocene

Annual accumulation of organic material (=loss on ignition), organic-carbon, Kjeldahl-nitrogen, phosphorus and the accumulation of sedimentary plant pigments are all used in interpreting the developmental changes in the productivity of Lake Wielkie Gacno.

As has been stressed by Vallentyne (1962), Ohle (1965) and Digerfeldt (1972) primary productivity is determined by the amount of available mineral nutrients, temperature and light. Decomposition of organic material takes place during sedimentation and in surface sediments while the organic material in the deeper sediments is thought to remain virtually unchanged.

The organic material in lake sediments may be both allochthonous and autochthonous. In Lake Wielkie Gacno changes in the supply of allochthonous organic material may have taken place during the different periods, but it is thought that these changes were on such a small scale that they have not substantially disturbed the annual accumulation of those indicators characteristic of lake productivity.

In Lake Wielkie Gacno productivity seems to have been relatively higher during the early lake development than after the Atlantic/Sub-boreal chronozone boundary. The highest productivity during the lake development is reached during the Middle and Late Atlantic chronozones.

From the beginning of the Sub-boreal chronozone productivity is progressively decreasing although, even so, values seem to stay at quite a high level. A distinct decrease in productivity occurs during the earlier part of the Sub-atlantic chronozone.

It is thought, on the basis of the water-level changes and diatom analyses that the lake basin was generally smaller and the water-level lower during the earlier part of the lake development. During this earlier period there is evidence of three lowerings of water-level. Thus, conditions allowing a greater supply of coarse organic material

were more common than during the Sub-boreal and Sub-atlantic chronozones. During the Sub-atlantic chronozone it is the decreased supply of nitrogen which is thought to have been the main limiting lake productivity. At the same time climatic deterioration commenced.

The relatively low but steady accumulation of nitrogen throughout the whole of the lake development is thought to be a function of the low productivity of the lake itself in contrast to the high and fluctuating values of phosphorus which are thought to be dependent on ground-water inflow. During the Atlantic chronozone the slight maxima of nitrogen and organic carbon occur somewhat before the distinct maximum of phosphorus. During the later part of the lake development the amounts of the Kjeldahl-nitrogen and organic carbon are generally decreasing while the accumulation of phosphorus is still high, although fluctuating strongly. Thus, it can be said that the actual productivity of Lake Wielkie Gacno has been fairly low and has gradually decreased towards recent times. On the contrary, the supply of nutrients and the ground-water inflow have been dependent on changes in ground-water level.

Iron and manganese (Fig. 52, Table 11)

The highest amounts of iron, calculated per unit dry weight, are found in the Pre-boreal chronozone (c. 5.5 mg/g DW). During the Boreal and Atlantic chronozones iron ranges between 2 and 3.5 mg/g DW. In the Early Atlantic chronozone there is, however, a temporary minimum of c. 1 mg/g DW, and in the later part of the Atlantic chronozone the amount of iron increases attaining values of 3.0 - 4.0 mg/g DW. During the later part of the lake development iron accumulation is fairly constant at around 2 mg/g DW, but in the Late Sub-atlantic chronozone values increase distinctly to exceed 5 mg/g dry weight.

Iron accumulation, calculated as annual deposition, varies between c. 100 mg and 180 mg/m² until the Atlantic/Sub-boreal chronozone boundary. In the lowermost samples, during the Early - middle part of the Pre-boreal chronozone, accumulation is more than 200 mg/m². During the later part of the lake development annual iron accumulation is reasonably constant (50 - 100 mg/m²), but then increases steadily during the latest part of the Late Sub-atlantic chronozone.

The amount of manganese, calculated as units dry weight, are fairly constant at around 0.1 mg/g DW. At the Middle/Late Sub-atlantic zone boundary the amounts increase suddenly to 0.17 - 0.2 mg/g DW. The annual accumulation of manganese shows only small changes throughout the whole of the lake development (around 0.5 mg/m² yr⁻¹).

The major source of iron and manganese supply to lakes is inflowing sub-soil water. Under aerobic conditions provided that the pH is not too high they are oxidized and deposited rather rapidly mainly as precipitates of ferric and manganese hydroxides. Ferric hydroxides will also form a microzone in the uppermost layers of the bottom sediment which functions as a barrier against the ionic diffusion exchange between the sediment

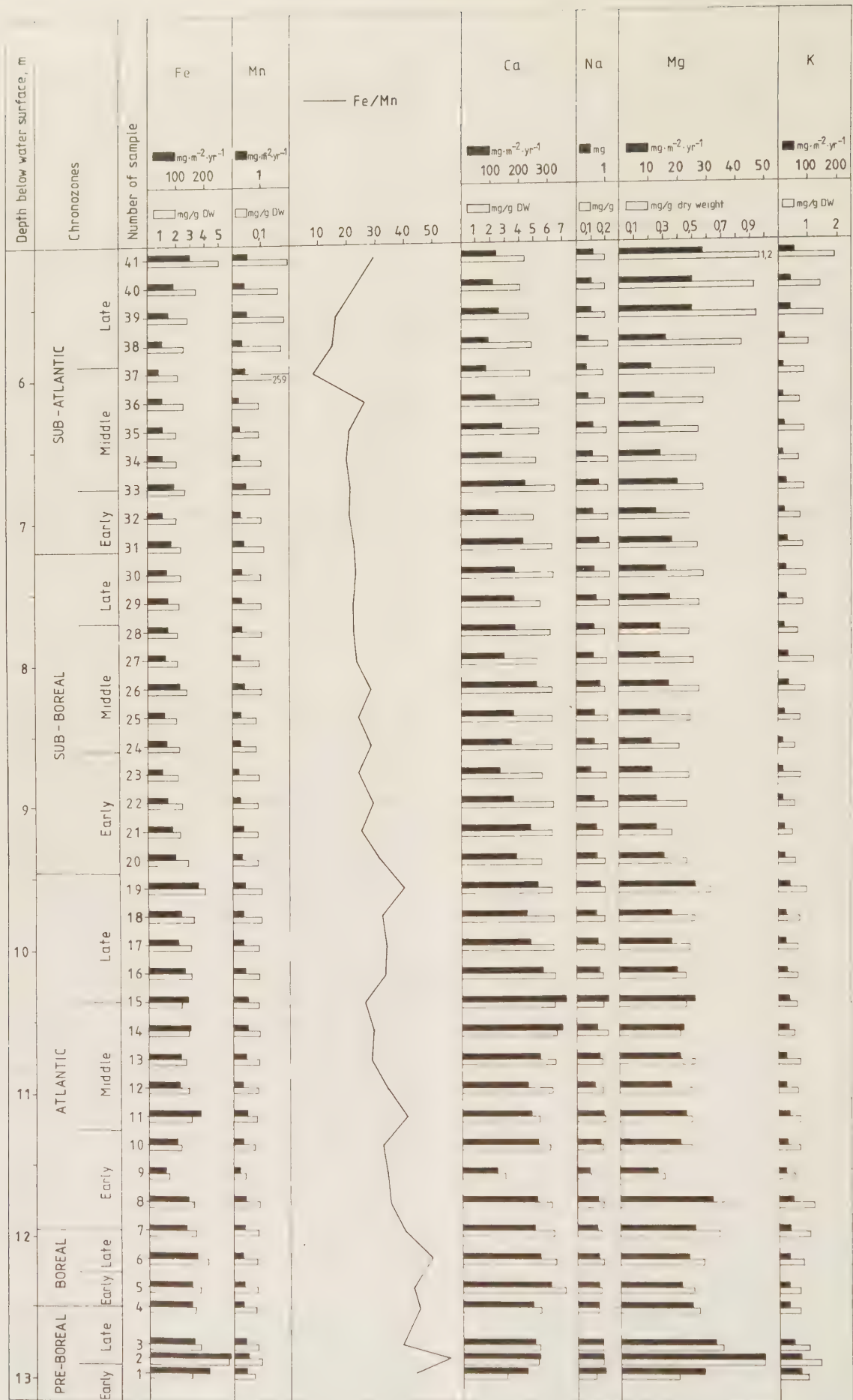


Figure 52. Sediment chemical analysis, Lake Wielkie Gacno, calculated per unit dry weight and per unit annual deposited sediment ($\text{g}/\text{mg}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$).

Table 11.

Depth below water surface, cm	Number of sample	Mn mg/g DW	Fe mg/g DW	Ca mg/g DW	Na mg/g DW	Mg mg/g DW	K mg/g DW
517	41	0.20	5.6	4.4	0.20	1.22	1.89
537	40	0.16	3.8	4.1	0.20	0.93	1.47
557	39	0.18	2.9	4.7	0.21	0.94	1.49
577	38	0.17	2.5	4.9	0.22	0.84	1.03
597	37	0.26	2.1	4.9	0.20	0.66	0.86
617	36	0.09	2.5	5.5	0.20	0.58	0.97
637	35	0.09	2.0	5.5	0.21	0.54	0.82
657	34	0.10	2.0	5.3	0.22	0.53	0.67
677	33	0.13	2.7	6.5	0.22	0.58	0.83
697	32	0.10	2.0	5.0	0.22	0.49	0.71
717	31	0.11	1.1	6.3	0.23	0.54	0.82
737	30	0.10	2.3	6.5	0.23	0.58	0.91
757	29	0.10	2.2	5.6	0.23	0.55	0.85
777	28	0.10	2.1	6.2	0.20	0.48	0.65
797	27	0.10	2.1	5.4	0.21	0.51	1.19
815	26	0.10	2.7	6.3	0.20	0.55	0.87
835	25	0.08	2.0	6.3	0.22	0.49	0.71
855	24	0.08	2.3	6.3	0.22	0.41	0.55
875	23	0.09	2.1	5.7	0.21	0.49	0.75
895	22	0.09	2.4	6.5	0.22	0.47	0.53
915	21	0.09	2.2	6.3	0.18	0.36	0.48
935	20	0.09	2.8	5.6	0.20	0.46	0.58
955	19	0.10	4.1	6.3	0.19	0.63	0.92
975	18	0.10	3.2	6.5	0.19	0.52	0.70
995	17	0.09	2.9	6.5	0.19	0.49	0.68
1015	16	0.08	2.9	6.5	0.18	0.46	0.63
1035	15	0.09	2.3	6.5	0.19	0.46	0.61
1055	14	0.09	2.7	6.7	0.22	0.43	0.56
1075	13	0.09	2.5	6.6	0.19	0.52	0.76
1095	12	0.09	2.9	6.3	0.19	0.50	0.68
1115	11	0.08	3.1	5.5	0.20	0.50	0.74
1135	10	0.07	2.3	6.1	0.19	0.50	0.72
1155	9	0.04	1.4	3.0	0.10	0.31	0.52
1175	8	0.09	3.3	6.2	0.19	0.78	1.19
1195	7	0.09	3.3	6.5	0.18	0.69	1.05
1215	6	0.08	4.2	6.6	0.18	0.58	0.84
1235	5	0.08	3.6	7.3	0.18	0.51	0.74
1250	4	0.08	3.3	5.6	0.17	0.55	0.78
1275	3	0.08	3.4	5.4	0.18	0.71	1.07
1285	2	0.10	5.7	5.4	0.18	1.00	1.42
1295	1	0.07	3.0	3.2	0.13	0.41	1.01

and the water. In palaeolimnological investigations from southern Sweden Digerfeldt (1972, 1975) has discussed in detail the significance and behaviour of iron in lake sediments to which reference can be made for more precise information.

The relatively higher amount of iron during the early and middle part of the lake development may be connected with the greater inflow of the sub-soil water (see Chapt. XI:3). The iron supply will also reflect changes in the ground water inflow (see the discussion in connection of P).

Any decrease in the inflow of sub-soil water due to compression of the compact gyttja against the minerogenic sediment of the lake bottom does not seem to have reached any great proportions during the early and middle part of the lake development. The lowering of water-level during the Sub-boreal and Sub-atlantic chronozones is scarcely reflected in the accumulation of iron and manganese. The increased supply of iron and manganese in the Late Sub-atlantic chronozone is thought to indicate the increased humidity of the climate and an increased leaching and subsoil water inflow during

recent time.

Variations of redox conditions in the sediment, which may result from the separation of iron and manganese are usually controlled by the Fe/Mn ratio (e.g. Mackareth 1966, Tessenow 1973, Digerfeldt 1975, 1977).

It is unlikely that the lake has even been under reducing conditions for in such a case the Fe-coloured sediments would have been formed. Slight fluctuations in the Fe/Mn ratio may indicate relatively strong lowerings in water-level in the lake with a greater inflow of subsoil water. During the Sub-boreal and the greater part of the Sub-atlantic chronozone a stable ratio indicates continued leaching of the soils. However, the soils were already poor in Fe and Mn, and the supply of these is increased only in connection with the rise in ground-water level and increased ground-water inflow into the lake.

Calcium, Sodium, Magnesium and Potassium (Fig. 52, Table 11)

Ca, Na, Mg and K are the major cation constituents in the lake water. They enter the sediment adsorbed or bound to the organic material which is being deposited. These cations are influenced by the ionic exchange equilibrium existing between the surface sediment and the lake water.

The concentration of Ca, Na, Mg and K in the sediment of Lake Wielkie Gacno is of following order: Ca K Mg Na. The amount of calcium calculated as unit dry weight increases slightly from the Pre-boreal chronozone up until the Middle/Late Atlantic chronozone boundary (from c. 3 mg to 6.5 mg/g DW). In the early part of the Sub-atlantic chronozone calcium accumulation remains steady at around 5.5 mg/g DW, and then decreases towards the most recent sediments by c. 2 mg/g DW.

The amount of sodium calculated as unit dry weight is constant around 0.2 mg/g DW throughout the whole lake development.

For the major part of the lake development the amount of magnesium calculated as unit dry weight fluctuates around 0.5 mg/g DW but in the Late Sub-atlantic chronozone the supply is distinctly greater, c. 0.9 mg/g DW.

The amount of potassium calculated as unit dry weight fluctuates between 0.6 mg and 1 mg/g DW for the greater part of the lake development and then increases during the Late Sub-atlantic chronozone to almost 2 mg/g dry weight.

Calcium is not so clearly associated with the products of mineral erosion and is more easily leached from the soils than magnesium and potassium. The distinctly higher accumulation rate of Ca in the sediment of Lake Wielkie Gacno may indicate that leaching from the surrounding soils has been fairly intensive throughout the whole of the lake development. The decreasing Ca amounts in the uppermost sediments show how easily Calcium leaches from the soils compared with other cations. It is to be expected that the amounts of Na, Mg and K will also decrease during the future lake development.

XIII. PALAEOECOLOGICAL SYNTHESIS FOR THE LAKE WIELKIE GACNO AREA

The main features of the Holocene vegetational development are illustrated in fig. 53 by a simplified AP-pollen diagram based on corrected pollen values (cf. Andersen 1973) for each tree species.

In interpreting such diagrams, the glacial and interglacial cyclic scheme of Iversen (1958) has often been applied. Iversen reworked and completed the theory of von Post (1946) concerning the correlation between climatic conditions and vegetation development. Iversen also emphasised the importance of soil development and the competition for light in this connection.

The vegetational changes in the area surrounding Lake Wielkie Gacno are synthesized by applying Iversen's palaeoecological model and terminology.

Full glacial time is followed by the protocratic stage of the Late-Glacial and the first part of the Holocene. During this time the low-competitive and light-demanding pioneer plants immigrated on to the neutral, unleached mostly minerogenic soils. Iversen advocated that the Pre-boreal period should also be included in the protocratic stage.

In the Wielkie Gacno area the protocratic stage of is assumed to have finished around the chrono-zone boundary Early/Late Pre-boreal. By that time *Corylus*, *Ulmus*, *Alnus* and even *Quercus* had immigrated. The steppe-vegetation with *Juniperus* had already retreated and almost totally disappeared somewhat earlier. The herb vegetation, indicating open communities and unleached soils (e.g. *Rumex* and *Artemisia*), and the vegetation which preferred moist meadows near waterbodies (e.g. *Filipendula*, Graminids and sedges) was only present a few individuals.

The pioneer stage was followed by a mesocratic stage comprising the greater part of the Holocene. In the beginning the immigrating forest trees were competing for growing space, and only reached a well-balanced condition gradually. Later when the climate reached its optimum, slightly acid soils developed and soil leaching began. According to Iversen (open cit.) the climax forests achieved their maximum shade during the Late Atlantic and Early Sub-boreal periods.

In the investigation area *Corylus* was as common as the *Quercetum mixtum* species during the Late Pre-boreal, Boreal and earlier part of the Early Atlantic chronozones. The climax forests developed during the Middle and Late Atlantic chronozones, a feature which is also indicated by the low pollen influx-values. During the time of the climax forests *Corylus* had to retreat to the marginal forest zone, *Ulmus* was as common as *Tilia*, but the *Quercetum mixtum* forests were dominated by *Quercus*, which has a greater life amplitude forming and was able to form associations with both *Pinus* and *Betula* on the one hand and with the other QM-species on the other. Herbs and graminids were found almost exclusively in the moister and more fertile broad-leaved forests and along the water sources.

The beginning of the last stage, the telocratic stage, is often placed at the beginning of retrogressive development in the forest vegetation. Accelerated leaching and soil degradation caused by increasing humidity and climatic deterioration are characteristic of this stage.

In Lake Wielkie Gacno area the boundary between the mesocratic and telocratic stages is not sharp. The nemoral broad-leaved forests reached their climax at the retrogressive forest development began around the Atlantic/Sub-boreal chronozone boundary. However, the transition phase was rather long. The representation of *Quercus* remained virtually unchanged. During the Sub-boreal chronozone it reached a somewhat higher representation than before, while *Ulmus*, *Tilia* and *Fraxinus* show a distinct

recession. At the Sub-boreal/Sub-atlantic chronozone boundary *Fagus* expanded with a simultaneous slight increase in *Betula*.

The human impact during the later part of the mesocratic and earlier part of the telocratic stages was fairly slight and its influence on the natural vegetation did not cause as great changes as did the climatic factors. Probably in the later part of the telocratic stage, is the first time, when human impact was so strong as to be the primary reason for large scale changes in the forest in the forest vegetation.

Because of the characteristic dune topography and the naturally poor, sandy soils, the vegetational development of the Lake Wielkie Gacno area is somewhat different from that of the forests in South Scandinavia. It is thought that, throughout the whole of the Holocene, the forest vegetation consisted of a mosaic of several different kinds of associations growing partly on the poor, sandy soils of the dunes and partly on the more fertile and favourable places between the dunes and along the rivers and lake shores.

The regional forest development is clearly seen in the pollen diagrams and it should be stressed that the nemoral broad-leaved forests were well developed even on the natural (that is, unaffected by man) soils of the Lake Wielkie Gacno area. However, the forest communities were more or less dominated by *Pinus* during the whole of the Holocene.

The succession was rather sensitive to the changes in the level of the ground-water. Because of this water-level changes have an important impact on the forest communities. Five major low-water periods have been established in Lake Wielkie Gacno. As a whole Lake Wielkie Gacno seems to have been considerably shallower during the earlier part of the Holocene, while during the Late Atlantic chronozone the lake became generally deeper and the level of the ground-water generally higher.

As is evident from the palaeolimnological results the productivity of the lake itself has been fairly low throughout the whole of its development and, because the soils around the lake are poor, it can be predicted that during the major part of the Holocene, the vegetation around the lake has obtained its nutrients from the ground-water. The phosphorus and carbonate contents of the lake sediment in particular were considerably higher during the Holocene than they are today, while the nitrogen content has remained low. Thus it is thought that nitrogen has been the limiting factor in lake productivity. The supply of the nutrients seems to have depended greatly on the fluctuations in ground water level and thus also on those of the lake water-level.

The Holocene succession of vegetation around Lake Wielkie Gacno in relation to soil and water conditions is schematically illustrated in Figs. 53. a-e.

In the Pre-boreal chronozone the organic layer in the soils was fairly thin and the ground-water level was relatively low. On the dune-slopes a mull horizon developed which, during the Boreal chronozone, became even thicker and appeared closer to the lake shores. On the dune-slopes a raw-humus horizon developed. The number of forest species was considerably higher than before. During the Atlantic chronozone especially, when the ground-water level is thought to have been higher, the nemoral broad-leaved associations were able to expand onto higher ground and *Pinus* was forced onto the poorest places, mainly on the higher dune-tops. During that time the mull layer of the sandy soils was thicker and richer in nutrients. Retrogressive development

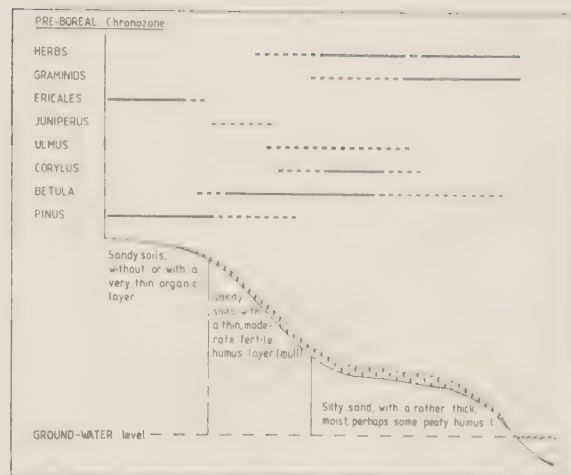
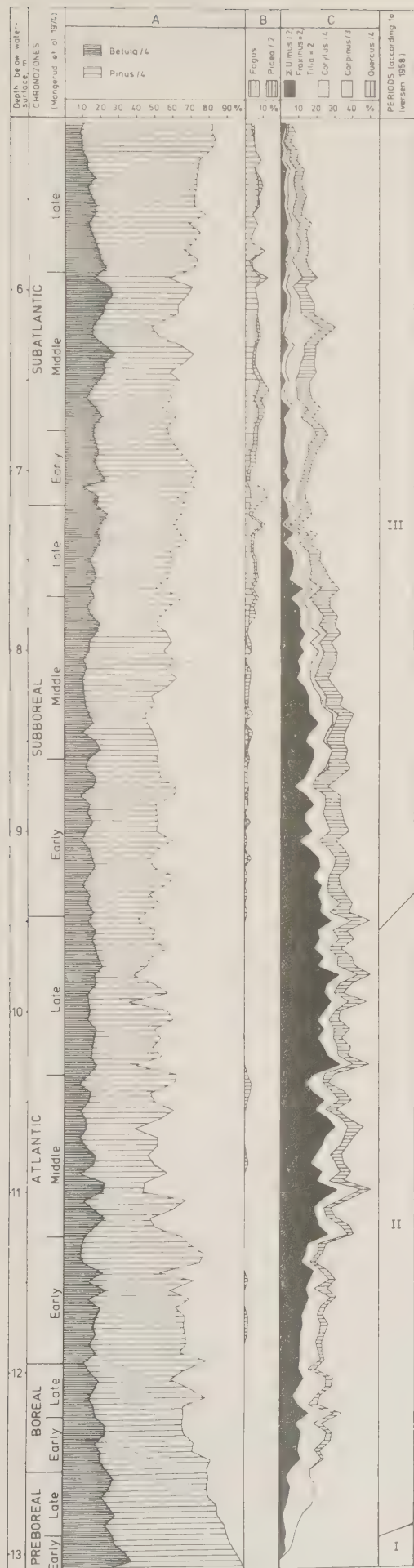


Figure 53.a.

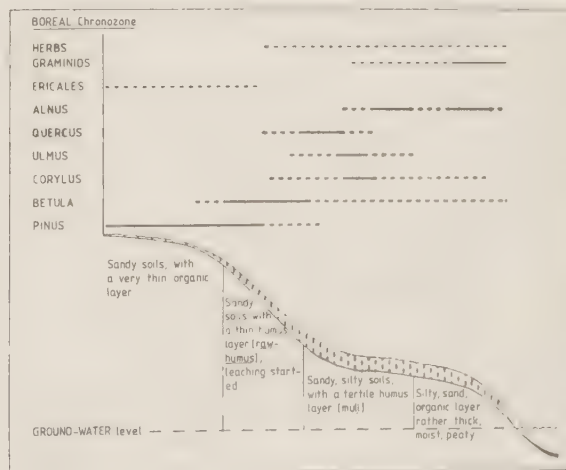


Figure 53.b

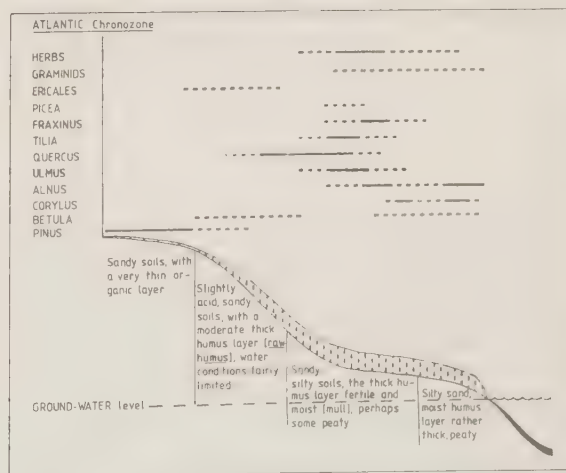


Figure 53.c.

Figure 53. Simplified AP-diagram, Lake Wiekie Gacno, based on corrected pollen values for each tree species.

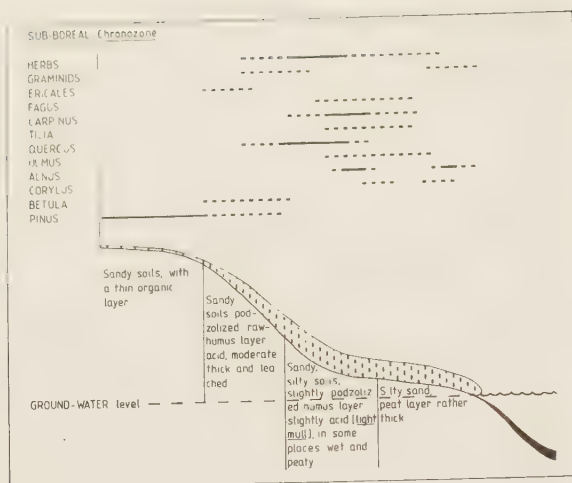


Figure 53.d.

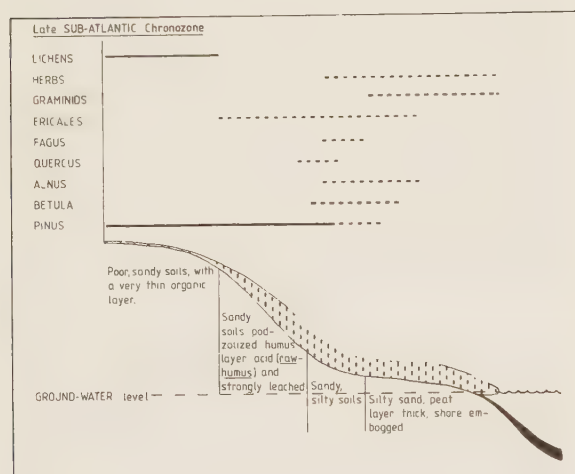


Figure 53.e

Figure 53. a-e. Holocene succession of vegetation around Lake Wielkie Gacno in relation to soil and water conditions (see the text on pp. 92 and 94); schematically illustrated.

of the forest vegetation started at the beginning of the Sub-boreal chronozone, and is thought partly to have caused the increased values for the pollen influx. This was probably due to climatic deterioration, more active soil leaching and human interference with the forests. On the higher places the mull layer became thinner and the broad-leaved forests which were not destroyed by man were forced onto the lower levels along the watercourses. Acidophilous Pineto-Quercetum association began to develop and, on the more mature places, Querco-Carpinetum associations began to appear. In the Middle and Late Sub-atlantic chronozones humidity increased and the exploitation of arable land resulted in accelerated erosion and soil leaching and thus a reduction in the nutrient capital. Except on the advantageous moister places between the dunes and along the watercourses the mull layer was very thin and such areas could no longer serve as agricultural land. The forests became naturally occupied by associations dominated by Pinus and were gradually

exploited for forestry purposes.

The modern forest communities of which the Vaccinium myrtilli-Pinetum is the most common, were largely formed artificially.

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